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SIR:

CERTIFIED TRANSLATION

I, Takashi Narita, am an official translator of the Japanese language into the English language and I hereby certify that the attached comprises an accurate translation into English of Japanese Application No. 2003-110836, filed on April 15, 2003.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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Takashi Narita

Takashi Narita

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[Inventor]	
[Address]	c/o Sony Corporation 7-35, Kitashinagawa 6-chome, Shinagawa-ku, Tokyo, Japan
[Name]	Tomonori Tsukagoshi
[Inventor]	
[Address]	c/o Sony Corporation 7-35, Kitashinagawa 6-chome, Shinagawa-ku, Tokyo, Japan
[Name]	Fumiaki Abe
[Inventor]	
[Address]	c/o Sony Corporation 7-35, Kitashinagawa 6-chome, Shinagawa-ku, Tokyo, Japan
[Name]	Kikuo Kaise
[Patent Applicant]	
[Identification Number]	000002185
[Name]	Sony Corporation
[Patent Attorney]	
[Identification Number]	100067736
[Patent Attorney]	
[Name]	Akira Koike
[Patent Attorney]	
[Identification Number]	100086335
[Patent Attorney]	

[Name]	Eiichi Tamura	
[Patent Attorney]		
[Identification Number]	100096677	
[Patent Attorney]		
[Name]	Seiji Iga	
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[Title of the Invention]

Liquid Crystal Display Device and Image Display Apparatus

[CLAIMS]

1 A liquid crystal display device having a microlens array provided on a luminous flux incidence side,

the liquid crystal display device comprising an optical compensation layer made of an inorganic material and having an optical axis inclined with respect to a liquid crystal panel surface, at least on one of the luminous flux incidence side and a luminous flux emission side of the liquid crystal panel.

2 The liquid crystal display device according to claim 1, wherein the inorganic material forming the optical compensation layer is uniaxial crystal.

3 The liquid crystal display device according to claim 2, wherein $\Delta n \cdot d$, which is the product of refractive index anisotropy Δn and thickness d of the inorganic material forming the optical compensation layer, is 640 nm or less.

4 The liquid crystal display device according to claim 2, wherein the inorganic material forming the optical compensation layer is crystal or sapphire.

5 The liquid crystal display device according to claim 4, wherein $\Delta n \cdot d$, which is the product of refractive index anisotropy Δn and thickness d of the inorganic material forming the optical compensation layer, is 640 nm or less.

6 The liquid crystal display device according to claim 1, wherein the direction

of projection of optical axis of the optical compensation layer to the liquid crystal panel surface is substantially parallel to at least one of the direction of projection of pre-tilt of liquid crystal molecules near a board surface on the luminous flux incidence side of the liquid crystal panel to the board surface and the direction of projection of pre-tilt of liquid crystal molecules near the board surface on the luminous flux side of the liquid crystal panel to the board surface.

7 The liquid crystal display device according to claim 6, wherein when refractive index anisotropy of the inorganic material forming the optical compensation layer and refractive index anisotropy of a liquid crystal layer of the liquid crystal panel have the same sign, the optical axis of the optical compensation layer and the optical axis of the liquid crystal layer are inclined in directions opposite to each other with respect to the liquid crystal panel surface.

8 The liquid crystal device according to claim 6, wherein when refractive index anisotropy of the inorganic material forming the optical compensation layer and refractive index anisotropy of a liquid crystal layer of the liquid crystal panel have different signs, the optical axis of the optical compensation layer and the optical axis of the liquid crystal layer are inclined in the same direction with respect to the liquid crystal panel surface.

9 The liquid crystal display device according to claim 1, wherein the optical compensation layers are provided on both the luminous flux incidence side and the luminous flux emission side of the liquid crystal panel, and

the direction of projection of optical axis of each of the optical compensation layers to the liquid crystal panel surface is substantially parallel to the direction of projection of pre-tilt of liquid crystal molecules near a board surface on the luminous flux incidence side of the liquid crystal panel to the board surface and the direction of projection of pre-tilt of liquid crystal molecules near the board surface on the luminous flux emission side of the liquid crystal panel to the board surface.

10 The liquid crystal display device according to claim 1, wherein the optical compensation layer has an outer size equal to or larger than an effective display area of the liquid crystal panel.

11 The liquid crystal display panel according to claim 1, wherein the optical compensation layer is provided on a dustproof glass provided on the surface of the liquid crystal panel.

12 The liquid crystal display device according to claim 1, wherein the optical compensation layer is provided on a cover glass of the microlens array.

13 A liquid crystal display device having a microlens array provided on a luminous flux incidence side,

the liquid crystal display device comprising two optical compensation layers made of an inorganic material and having an optical axis inclined with respect to a liquid crystal panel surface, on the luminous flux incidence side of the liquid crystal panel.

14 An image display apparatus comprising:

a light source;

a liquid crystal display device having a microlens array provided on a luminous flux incidence side serving as a spatial light modulator;

an illuminating optical system for guiding a luminous flux emitted from the light source to the liquid crystal display device and thus illuminating the liquid crystal display device; and

an image-forming lens for forming an image of the liquid crystal display device;

the liquid crystal display device comprising an optical compensation layer made of an inorganic material and having an optical axis inclined with respect to a liquid crystal panel surface, at least on one of the luminous flux incidence side and a luminous flux emission side of the liquid crystal panel.

15 The image display apparatus according to claim 14, wherein the inorganic material forming the optical compensation layer of the liquid crystal display device is uniaxial crystal.

16 The image display apparatus according to claim 15, wherein $\Delta n \cdot d$, which is the product of refractive index anisotropy Δn and thickness d of the inorganic material forming the optical compensation layer of the liquid crystal display device, is 640 nm or less.

17 The image display apparatus according to claim 15, wherein the inorganic material forming the optical compensation layer of the liquid crystal device is

crystal or sapphire.

18 The image display apparatus according to claim 17, wherein $\Delta n \cdot d$, which is the product of refractive index anisotropy Δn and thickness d of the inorganic material forming the optical compensation layer of the liquid crystal display device, is 640 nm or less.

19 The image display apparatus according to claim 14, wherein the direction of projection of optical axis of the optical compensation layer of the liquid crystal display device to the liquid crystal panel surface is substantially parallel to at least one of the direction of projection of pre-tilt of liquid crystal molecules near a board surface on the luminous flux incidence side of the liquid crystal panel to the board surface and the direction of projection of pre-tilt of liquid crystal molecules near the board surface on the luminous flux emission side of the liquid crystal panel to the board surface.

20 The image display apparatus according to claim 19, wherein when refractive index anisotropy of the inorganic material forming the optical compensation layer of the liquid crystal display device and refractive index anisotropy of a liquid crystal layer of the liquid crystal panel have the same sign, the optical axis of the optical compensation layer and the optical axis of the liquid crystal layer are inclined in directions opposite to each other with respect to the liquid crystal panel surface.

21 The image display apparatus according to claim 19, wherein when refractive

index anisotropy of the inorganic material forming the optical compensation layer of the liquid crystal display device and refractive index anisotropy of a liquid crystal layer of the liquid crystal panel have different signs, the optical axis of the optical compensation layer and the optical axis of the liquid crystal layer are inclined in the same direction with respect to the liquid crystal panel surface.

22 The image display apparatus according to claim 14, wherein the optical compensation layers of the liquid crystal display devices are provided on both the luminous flux incidence side and the luminous flux emission side of the liquid crystal panel, and

the direction of projection of optical axis of each of the optical compensation layers to the liquid crystal panel surface is substantially parallel to the direction of projection of pre-tilt of liquid crystal molecules near a board surface on the luminous flux incidence side of the liquid crystal panel to the board surface and the direction of projection of pre-tilt of liquid crystal molecules near the board surface on the luminous flux emission side of the liquid crystal panel to the board surface.

23 The image display apparatus according to claim 14, wherein the optical compensation layer of the liquid crystal display device has an outer size equal to or larger than an effective display area of the liquid crystal panel.

24 The image display apparatus according to claim 14, wherein the optical compensation layer of the liquid crystal display device is provided on a dustproof glass provided on the surface of the liquid crystal panel.

25 The image display apparatus according to claim 14, wherein the optical compensation layer of the liquid crystal display device is provided on a cover glass of the microlens array.

26 An image display apparatus comprising:

a light source;

a liquid crystal display device having a microlens array provided on a luminous flux incidence side serving as a spatial light modulator;

an illuminating optical system for guiding a luminous flux emitted from the light source to the liquid crystal display device and thus illuminating the liquid crystal device; and

an image-forming lens for forming an image f the liquid crystal display device;

the liquid crystal display device comprising two optical compensation layers made of an inorganic material and having an optical axis inclined with respect to a liquid crystal panel surface, on the luminous flux incidence side of the liquid crystal panel.

[Detailed Description of the Invention]

[0001]

[Field of the Invention]

This invention relates to a liquid crystal display device serving as a spatial light modulator, and an image display apparatus caused to be of the configuration

in which such liquid crystal display device is used as a spatial light modulator.

[0002]

[Prior Art]

Hitherto, there are proposed image display apparatuses caused to be of the configuration in which liquid crystal display device is used as a spatial light modulator.

[0003]

Such an image display apparatus is caused to be of the configuration including an illuminating optical system for irradiating a luminous flux from a light source onto a liquid crystal device to illuminate the liquid crystal display device, and an image-forming optical system for forming an image of the liquid crystal display device on a screen.

[0004]

In such an image display apparatus, higher contrast and higher luminance of displayed images are demanded. It is also demanded that the apparatus has a longer life. In such a liquid crystal display device, a microlens array for condensing or converging an incident luminous flux onto an effective display area part of the liquid crystal display device is provided to realize higher luminance of displayed images.

[0005]

[Patent Reference 1: JP-A-2001-343623

[0006]

[Problems to be solved by the invention]

As the above-described liquid crystal display device, so-called TN (twisted nematic) liquid crystal is broadly used. In the image display apparatus using this TN liquid crystal, the influence of pre-tilt of liquid crystal molecules on the interface between a liquid crystal layer and a board of the liquid crystal display device causes occurrence of a so-called "black prominence" phenomenon that a part where black should be displayed has lightness at the time of voltage application (black display) to the liquid crystal device, and therefore the contrast is lowered. Particularly when a microlens array is provided on the luminous flux incidence side of the liquid crystal display device, such "black prominence" phenomenon remarkably appears.

[0007]

Measures to prevent such a phenomenon are proposed such as arrangement of a broader visual angle film made of discotic liquid crystal (for example, "WV film" (trade name) of Fuji Photo Film) as described in the Patent Reference 1, near the liquid crystal display device, and arrangement of a uniaxial phase-difference film in an inclined state near the liquid crystal display device. The broader visual angle film or uniaxial phase-difference film compensates double refraction due to the pre-tilt angle of the liquid crystal molecules so that higher contrast of displayed images is realized.

[0008]

However, in the case where the broader visual angle film formed by discotic liquid crystal is used, there is a problem about the life time of this broader visual angle film. Specifically, the life of the broader visual angle film is not long enough to correspond to the life of the image display apparatus, which is assumed to be several thousands hours. If the output of the light source is increased to realize higher luminance of display images, the life time of the broader visual angle film becomes much shorter.

[0009]

On the other hand, if the uniaxial phase-difference film is installed in an inclined state near the liquid crystal display device, a large space is needed for installing the uniaxial phase-difference film and the structure of the image display apparatus is increased in size.

[0010]

Thus, in view of the foregoing status of the art, it is an object of this invention to provide a liquid crystal display device that does not increase the size of the structure of an image display apparatus when it is used as a spatial light modulator in the image display apparatus and that can realize higher contrast of display images while maintaining a sufficiently long life time, and an image display apparatus caused to be of the configuration in which such a liquid crystal display device is used.

[0011]

[Means for solving the problems]

To solve the above-described problems, a liquid crystal display device according to this invention is a liquid crystal display device having a microlens array provided on a luminous flux incidence side, and the liquid crystal display device comprises an optical compensation layer made of an inorganic material and having an optical axis inclined with respect to a liquid crystal panel surface, at least on one of a luminous flux incidence side and a luminous flux emission side of the liquid crystal panel.

[0012]

Moreover, another liquid crystal display device according to this invention has a microlens array provided on a luminous flux incidence side. The liquid crystal display device comprises two optical compensation layers made of an inorganic material and having an optical axis inclined with respect to a liquid crystal panel surface, on the luminous flux incidence side of the liquid crystal panel.

[0013]

In the case where these liquid crystal display devices according to this invention are used as a spatial light modulator in an image display apparatus, higher luminance of displayed images can be realized by the microlens array. In addition to this, the influence of pre-tilt of liquid crystal molecules in the liquid crystal panel

can be optically compensated by the optical compensation layer(s), thus realizing higher contrast of displayed images and a longer life time. Moreover, since the inorganic material having high light resistance is used as the optical compensation layer(s), higher luminance of displayed images due to large output of a light source of the image display apparatus can be realized. If sapphire or crystal, both of which have high thermal conductivity, is used as the inorganic material, rise in the temperature of the liquid crystal panel can be suppressed.

[0014]

Further, an image display apparatus according to this invention has a light source, a liquid crystal display device having a microlens array provided on a luminous flux incidence side serving as a spatial light modulator, an illuminating optical system for guiding a luminous flux emitted from a light source to the liquid crystal display device and thus illuminating the liquid crystal display device, and an image-forming lens for forming an image of the liquid crystal display device. The liquid crystal display device comprises an optical compensation layer made of an inorganic material and having an optical axis inclined with respect to a liquid crystal panel surface, at least on one of a luminous flux incidence side and a luminous flux emission side of the liquid crystal panel.

[0015]

Another image display apparatus according to this invention comprises a light source, a liquid crystal display device having a microlens array provided on a

luminous flux incidence side serving as a spatial light modulator, an illuminating optical system for guiding a luminous flux emitted from the light source to the liquid crystal display device to illuminate the liquid crystal display device, and an image-forming lens for forming an image of the liquid crystal display device, wherein the liquid crystal display device comprises two optical compensation layers made of an inorganic material and each having an optical axis inclined with respect to a liquid crystal panel surface on the luminous flux incidence side of the liquid crystal panel.

[0016]

In these image display apparatuses according to this invention, higher luminance of displayed images can be realized by the microlens array provided at the liquid crystal display device, and the influence of pre-tilt of liquid crystal molecules in the liquid crystal panel is optically compensated by the optical compensation layer(s). Higher contrast of display images is realized and also a longer life time is realized. Moreover, since the inorganic material having high light resistance is used as the optical compensation layer(s), higher luminance of displayed images due to large output of the light source of the image display apparatus can be realized. If sapphire or crystal, both of which have high thermal conductivity, is used as the inorganic material, rise in the temperature of the liquid crystal display device can be suppressed.

[Best Mode for Carrying Out the Invention]

Embodiments of this invention will now be described with reference to the drawings.

[0018]

[Structure of Liquid Crystal Display Device]

In a liquid crystal display device according to this invention, an incidence-side dustproof glass 1 (made of quartz with a thickness of 1.0 mm), a microlens board 2 (made of quartz with a thickness of 1.0 mm), and a TFT board 3 (made of quartz with a thickness of 1.1 mm) are laminated in order from the luminous flux incidence side, and a first optical compensation plate 4 (made of sapphire) serving as an optical compensation layer for optically compensating an emission-side pre-tilt component, an emission-side dustproof glass 5 (made of quartz with a thickness of 1.0 mm), and a second optical compensation plate 6 (made of sapphire) for optically compensating an incidence-side pre-tilt component are laminated in order toward the luminous flux emission side, as shown in Fig.1.

[0019]

A microlens array 7 is formed on the TFT board 3 side of the microlens board 2. A liquid crystal panel formed by sealing liquid crystal molecules is arranged within the TFT board 3. A major surface of the liquid crystal panel on the luminous flux incidence side faces the microlens array 7, as a liquid crystal panel surface 8.

[0020]

The first optical compensation plate 4 serves to compensate the optical influence due to the pre-tilt angle of liquid crystal molecules on the luminous flux emission side of the liquid crystal panel. The second optical compensation plate 6 serves to compensate the optical influence due to the pre-tilt angle of liquid crystal molecules on the luminous flux incidence side of the liquid crystal panel. Whether these optical compensation plates 4, 6 are arranged on the luminous flux incidence side or the luminous flux emission side of the liquid crystal panel, and in whatever order, the optical compensation plates 4, 6 have an effect of improving contrast of a displayed image in an image display apparatus, which will be described later.

[0021]

Each of the optical compensation plates 4, 6 is made of uniaxial crystal such as crystal or sapphire and formed in a flat plate-like shape. Each of the optical compensation plates 4, 6 has its optical axis inclined with respect to the liquid crystal panel surface 8. The direction of projection onto the liquid crystal panel surface 8 of the direction of the optical axis of each of the optical compensation plates 4, 6 is substantially parallel to at least either the direction of projection onto the liquid crystal panel surface 8 of the direction of pre-tilt of liquid crystal molecules near the board surface on the luminous flux incidence side of the liquid crystal panel or the direction of projection onto the liquid crystal panel surface 8 of the direction of pre-tilt of liquid crystal molecules near the board surface on the

luminous flux emission side of the liquid crystal panel.

[0022]

The optimum angle of inclination of the optical axes of the optical compensation plates 4, 6 with respect to the liquid crystal panel surface 8 can be found by simulating transmittance at the time of voltage application (so-called "black display") to the liquid crystal panel. This simulation can be performed, for example, using a liquid crystal simulator "LCD Master" (trade name) made by SHINTEC INC. The angle of inclination of the optical axes of the optical compensation plates 4, 6 with respect to the liquid crystal panel surface 8 is defined so that the direction along (parallel to) the liquid crystal panel surface is at 0°, as shown in Fig.2.

[0023]

The simulation was performed using dielectric constants (ε11, ε22, ε33), elastic constants (K11, K22, K33), rotational viscosity, helical pitch, pre-tilt angle on an orientation film surface, liquid crystal cell gap, and twist angle based on a liquid crystal material "MJ99200" (trade name) made by "Merck Ltd.". Liquid crystal director distribution at the time of applying a predetermined voltage was calculated. On the basis of the distribution, the ordinary ray refractive index (no) and extraordinary ray refractive index (ne) of the liquid crystal, and the ordinary ray refractive index (no) and extraordinary ray refractive index (ne) of sapphire as the characteristics of the optical compensation plates were used. The thickness of

the optical compensation plates was 20 μm. Both the optical compensation plates 4, 6 were arranged on the luminous flux emission side of the liquid crystal panel, as shown in Fig.1.

[0024]

Then, using an optical model formed by combining the liquid crystal display device and a polarizing plate, the incident angle dependence of the transmittance of a propagating ray with a wavelength of 550 nm was found by a 4×4 matrix technique.

[0025]

For the transmittance, on the assumption that the incidence angle of a luminous flux was 5°, 10° and 15°, the direction of the optical axes of the optical compensation plates was equally divided every 5° into 72 directions with the rubbing direction on the luminous flux incidence side of the liquid crystal panel being as reference, and the average transmittance thereof was regarded as the transmittance at each incident angle. As shown in Fig.3, the ratio of transmittance in "black display" between the case of using only the liquid crystal panel and the case of arranging the optical compensation plates was found.

[0026]

By optimizing the angle of inclination of the optical axes of the optical compensation plates with respect to the liquid crystal panel surface 8 on the basis of this result, it is possible to sufficiently reduce the transmittance in "black display".

As shown in Fig.3, an optimum angle of inclination of the optical axes of the optical compensation plates is approximately 75° to 85°.

[0027]

In this liquid crystal display device, since the microlens array is arranged on the luminous flux incidence side of the liquid crystal panel, the incident angle of the luminous flux to the liquid crystal panel is different from the emission angle of the luminous flux from the liquid crystal panel and therefore the above-described simulation conditions are slightly different from the conditions in the actual optical system. However, in the image display apparatus using the liquid crystal display device, since the incident angle of the luminous flux to the liquid crystal panel is approximately 13° to 14°, the difference in the optimum angle of the optical axes of the optical compensation plates caused by the difference between the above-described simulation conditions and the conditions in the actual optical system is small. Therefore, it can be said that the two optical compensation plates 4, 6 having the inclined optical axes are arranged as described above so that the contrast of a displayed image is improved.

[0028]

Also in the case where the arrangement positions of the two optical compensation plates 4, 6 are replaced with each other, it is possible to reduce the transmittance in "black display" by setting the optical axes at the optimum angle of inclination, as shown in Fig.4.

[0029]

From these results, it was found that the two optical compensation plates 4, 6 can improve the contrast of a displayed image if they are arranged to optically compensate the pre-tilt component on the luminous flux incidence side of the liquid crystal panel and the pre-tilt component on the luminous flux emission side, irrespective of their arrangement order.

[0030]

That is, one of the two optical compensation plates 4, 6 may be arranged on the luminous flux incidence side of the liquid crystal panel and the other may be arranged on the luminous flux emission side, as shown in Fig.5. The optical compensation plates 4, 6 may be formed on the major surfaces of the incidence-side dust proof glass 1 and the emission-side dustproof glass 5, or may be formed as the microlens board 2 (cover glass of the microlens array).

[0031]

Now, in the case where the optical compensation plates are formed by sapphire, the transmittance ratio in "black display" when changing the thickness of the optical compensation plates from 20 to 80 μm is sufficiently suppressed even when the thickness is 80 μm if the incident angle to the liquid crystal panel is 5°, as shown in Fig.6. The transmittance ratio represented by the ordinate in Fig.6 is the ratio of the transmittance in the case where the optical compensation plates are arranged to the transmittance in the case where the optical compensation plates are

not arranged. If the transmittance ratio is less than 1, it means that the transmittance is reduced by the arrangement of the optical compensation plates and that the contrast of the displayed image is improved. The angle of inclination of the optical axes of the optical compensation plates in this case is 80°.

[0032]

An absolute value Δn of refractive index anisotropy of sapphire is substantially 0.008 in each wavelength range. When the thickness d of the sapphire plates is 80 μm, Δn·d is approximately 640 nm. If Δn·d is more than 640 nm with respect to the optical compensation plates, double refraction by the optical compensation plates becomes dominant in the transmittance of "black display". The transmittance increases, causing a "black prominence" phenomenon. From this result, it is desired that Δn·d is equal to or less than 640 nm with respect to one optical compensation plate.

[0033]

In the case where the refractive index anisotropy of the optical compensation plates and the refractive index anisotropy of the liquid crystal layer of the liquid crystal panel have difference signs, as in the case where the optical compensation plates are formed by sapphire, the optical axes of the optical compensation plates and the optical axis of the liquid crystal layer should be inclined in the same direction with respect to the liquid crystal panel surface, as shown in Fig.7.

[0034]

On the other hand, in the case where the refractive index anisotropy of the optical compensation plates and the refractive index anisotropy of the liquid crystal layer of the liquid crystal panel have the same sign, as in the case where the optical compensation plates are prepared by crystal, the optical axes of the optical compensation plates and the optical axis of the liquid crystal layer should be inclined in the directions opposite to each other with respect to the liquid crystal panel surface, as shown in Fig.8.

[0035]

[Preparation of Liquid Crystal Display Device (1)]

A method for preparing the liquid crystal display device according to this invention will now be described.

[0036]

First, a liquid crystal panel of a predetermined standard, for example, the following standard, is prepared by arranging a microlens array on the incidence side. Specifically, a liquid crystal cell of the "XGA" standard having an effective pixel size (diagonal line) of 0.9 inches and a pixel pitch of 18 μm is prepared. The liquid crystal cell is prepared by carrying out application of an orientation film, rubbing processing, and arrangement of a spacer at a rubbing angle of 90°, a twist angle of 90° and with a cell gap of 3.2 μm. Liquid crystal ("MJ99200" (trade name) made by Merck Ltd.) is injected therein to complete the liquid crystal cell.

[0037]

Next, for preparing an optical compensation plate, first at step st1 as shown in the flowchart of Fig.9, the crystal orientation is identified, for example, by X-ray diffraction with respect to a sapphire single-crystal block as shown in Figs.10(a) and 10(b). Next, at step st2 in Fig.9, a sapphire plate is cut out by using a diamond cutter so that the angle of inclination of its optical axis to the surface of the sapphire single-crystal block becomes 60°, 70°, 80°, and 90°, as shown in Fig.10(c). Then, at step st3 in Fig.9, a sapphire plate having a predetermined thickness and size is cut out by using the diamond cutter.

[0038]

In this cutting-out process, a sapphire plate having a thickness of approximately 25 μm is cut out. Moreover, in this cutting-out process, the direction of inclination of the optical axis with respect to the rectangular glass shape is caused to coincide with the rubbing direction of the liquid crystal panel so that a pre-tilt component in the liquid crystal panel can be optically compensated, as shown in Fig.11. Further, the optical compensation plate cut out in this case has a size large enough to cover the effective pixels of the liquid crystal panel.

[0039]

At step st4 in Fig.9, an adhesive is applied onto the surface of a quartz glass, which is a dustproof glass or the like, by so-called spin coat technique in a reduced-pressure chamber. As the adhesive, for example, silicon resin, epoxy resin, acrylic resin, or fluororesin is applied.

[0040]

Next, at step st5, the optical compensation plate is laminated to the predetermined dustproof glass or the like in a predetermined direction. At step st6, the adhesive is hardened. The adhesive is hardened by heating or by irradiating ultraviolet (UV) rays. If two optical compensation plates are used, these steps st4 to st6 are carried out twice. At step st7, the sapphire plate is ground and polished to a thickness of 20 μm. The dustproof glass with the optical compensation plate arranged thereon is thus prepared.

[0041]

In Fig.11(a), the first optical compensation plate 4 for compensating a pre-tilt on the emission side of the liquid crystal panel is arranged on the luminous flux incidence side, and the second optical compensation plate 6 for compensating a pre-tilt on the incidence side of the liquid crystal panel is arranged on the luminous flux emission side. In Fig.11(b), the second optical compensation plate 6 for compensating a pre-tilt on the incidence side of the liquid crystal panel is arranged on the luminous flux incidence side, and the first optical compensation plate 4 for compensating a pre-tilt on the emission side of the liquid crystal panel is arranged on the luminous flux emission side.

[0042]

After that, a dustproof glass having no optical compensation plate arranged thereon is attached to the luminous flux incidence side. On the luminous flux

emission side, a dustproof glass having no optical compensation plate arranged thereon and the dustproof glass having the optical compensation plate arranged thereon are arranged in a predetermined direction as shown in Figs.11A and 11B. Moreover, a flexible board 9 to be connected to the TFT board is attached and, for example, a metal frame 10 is fit thereon and a finishing plate 11 is attached, as shown in Fig.12. The liquid crystal display device that can be used in the image display apparatus is thus completed.

[0043]

[Measurement of Contrast in Displayed Image on Image Display Apparatus]

The image display apparatus according to this invention using the liquid crystal display device as described above has a light source 12 such as a discharge lamp, as shown in Fig.13. Luminous fluxes emitted from the light source 12 are reflected by a concave mirror (parabolic mirror) 13 so that there result in substantially parallel luminous fluxes, then transmitted through a UV (ultraviolet)/IR (infrared) cut filter 14 and a first fly-eye lens array 15, then reflected by a mirror 16 and become incident on a second fly-eye lens array 17. As the result of the fact that the luminous fluxes having substantially uniform lightness by being transmitted through the first and second fly-eye lens arrays 15 and 17 are transmitted through a PS combination device 18, the luminous fluxes have a predetermined direction of polarization.

[0044]

The PS combination device 18 has plural polarized light separation films parallel to each other. P-polarized light components of the incident luminous fluxes on the PS combination device 18 are transmitted through the polarized light separation films. S-polarized light components of the incident luminous fluxes on the PS combination device 18 are reflected twice by the polarized light separation films and then emitted. These P-polarized light component and S-polarized light components are emitted parallel to each other but their emitting positions are separated. A half-wavelength ($\lambda/2$) plate is arranged at either the emitting position of the P-polarized light components or the emitting position of the S-polarized light components to rotate the direction of polarization by 90°. In this manner, the emitted rays of light from the PS combination device 18 have the same direction of polarization.

[0045]

The emitted light from the PS combination device 18 is transmitted through a condenser lens 19 and becomes incident on a first dichroic mirror 20. The first dichroic mirror 20 reflects one of the three primary colors (R, G, B) and transmits the other two colors.

[0046]

The luminous fluxes transmitted through the first dichroic mirror 20 become incident on a second dichroic mirror 21. The second dichroic mirror 21 reflects one of the two primary colors transmitted through the first dichroic mirror 20 and

transmits the remaining one color (first color).

[0047]

The luminous flux transmitted through the second dichroic mirror 21 is transmitted through a relay lens 22, a mirror 23, a relay lens 24 and a mirror 25 and then through a field lens 26 and a polarizing plate 27, and becomes incident on a first liquid crystal display device 28. This luminous flux is polarization-modulated in accordance with the first color component of the displayed image by the first liquid crystal display device 28 and is then transmitted. The luminous flux is transmitted through a polarizing plate 29 and becomes incident on a cross prism 30 form its one lateral side.

[0048]

The luminous flux of the one color (second color) reflected by the second dichroic mirror 21 is transmitted through a field lens 36 and a polarizing plate 37 and becomes incident on a second liquid crystal display device 38. This luminous flux is polarization-modulated in accordance with the second color component of the displayed image by the second liquid crystal display device 38 and is then transmitted. The luminous flux is transmitted through a polarizing plate 39 and becomes incident on the cross prism 30 from its rear side.

[0049]

The luminous flux of the one color (third color) reflected by the first dichroic mirror 20 is transmitted through a mirror 31, then through a field lens 32 and a

polarizing plate 33, and becomes incident on a third liquid crystal display device 34. This luminous flux is polarization-modulated in accordance with the third color component of the displayed image by the third liquid crystal display device 34 and is then transmitted. The luminous flux is transmitted through a polarizing plate 35 and becomes incident on the cross prism 30 from its other lateral side.

[0050]

Rays of light of the three primary colors incident on the cross prism 30 from the three sides are combined by this cross prism 30 and become incident on an image forming (projection) lens 40, which is an image-forming optical system. The image forming lens 40 projects the incident luminous flux on a screen, not shown, to display an image.

[0051]

In such an image display apparatus, the contrast ratio of the image projected on the screen is measured in the case where the liquid crystal display devices have optical compensation plates and in the case where the liquid crystal display devices do not have optical compensation plates. As shown in Fig.14, the contrast of the displayed image is improved to more degree in the case where the optical compensation plates are provided. In the image display apparatus that acquired this result, the F-value of the image forming lens of the optical system is 2.5.

[0052]

[Preparation of Liquid Crystal Display Device (2)]

In this liquid crystal display device, a microlens array can be prepared by process steps (1) to (4) shown in Fig.15.

[0053]

At the process step (1), quartz having a thickness of 1.5 mm is used as a substrate and the substrate is cleaned, for example, by an RCA cleaning technique. After that, a resist is applied corresponding to each pixel and exposure and development are performed. A resist mask that opens the center of each pixel in an appropriate shape is thus prepared.

[0054]

At the process step (2), for example, using HF or BHF, isotropic etching is performed to form spherical surfaces on the quartz substrate. The diameter of the spherical surface is made substantially equal to the pixel size, and the spacing between the centers of the spherical surfaces is made equal to the pixel pitch.

[0055]

At the process step (3), a resin having a refractive index that is different from the refractive index of the quartz is applied and then extended by a spin coat technique. A microlens array is thus prepared. As a cover glass, an optical compensation plate having a thickness greater than a predetermined thickness is prepared by the above-described process of Fig.9. The angle of inclination of its optical axis set to 60°, 70°, 80° and 90°. The sapphire board has a thickness of approximately 25 μm.

[0056]

The optical compensation plate is arranged at a position where it can optically compensate a pre-tilt component on the incidence side, and the optical compensation plate is attached to the microlens array. After that, the quartz glass and the sapphire plate are ground and polished to a predetermined thickness. In this case, the sapphire plate is ground and polished to a thickness of 20 μm.

[0057]

In the process step (4), an ITO film is formed on the cover glass by a sputtering technique, thus preparing a microlens board.

[0058]

In the liquid crystal panel, the microlens array is arranged on the incidence side, as in the above-described case. The liquid crystal panel is prepared, for example, in accordance with the following predetermined standard. Specifically, a liquid crystal cell of "XGA" standard having an effective pixel size (diagonal line) of 0.9 inches and a pixel pitch of 18 μm is prepared. Application of an orientation film, rubbing processing, and arrangement of a spacer are carried out at a rubbing angle of 90°, a twist angle of 90° and a cell gap of 3.2 μm, and liquid crystal ("MJ99200" (trade name) made by Merck Ltd.) is injected. The liquid crystal cell is thus completed.

[0059]

In this manner, the liquid crystal display device is completed as shown in

Fig.5. Each optical compensation plate is arranged in such a manner that the angle of inclination of the optical axis of the optical compensation plate on the luminous flux incidence side is equal to the angle of inclination of the optical axis of the optical compensation plate on the luminous flux emission side. In this case, the angle of inclination of the optical axis of the optical compensation plate for compensating a pre-tilt component on the luminous flux incidence side need not be coincident with the angle of inclination of the optical axis of the optical compensation plate for compensating a pre-tilt component on the luminous flux emission side.

[0060]

Moreover, the flexible board 9 to be connected to the TFT board is attached and, for example, the metal frame 10 is fit thereon and the finishing plate 11 is attached, as shown in Fig.12. The liquid crystal display device that can be used in the image display apparatus is thus completed.

[0061]

For the liquid crystal display device formed as described above, the contrast ratio of the image projected on the screen is measured in the case where the liquid crystal display devices have optical compensation plates and in the case where the liquid crystal display devices do not have optical compensation plates, using the optical system of the image display apparatus described with reference to Fig.13. As shown in Fig.16, it is understood that the contrast of the displayed image is

improved to much degree in the case where the optical compensation plates are provided. In the image display apparatus that acquired this result, the F-value of the image forming lens of the optical system is 2.5.

[0062]

[Preparation of Liquid Crystal Display Device (3)]

First, as in the case described with reference to Fig.15, spherical surfaces each having a diameter substantially equal to the pixel size are formed at a spacing (between the centers of the spherical surfaces) equal to the pixel pitch, on a quarts substrate. Then, a resin having a refractive index of 1.60 is applied and extended by a spin coat technique, as shown in Fig.17. In this case, the number of rotations and the rotation time are optimized so that the thickness shown as "resin thickness" in Fig.17 becomes 10 μm. Then, as a cover glass, an optical compensation plate having a thickness greater than a predetermined thickness is prepared by the process which has been described with reference to Fig.9. The optical compensation plate is prepared so that the angle of inclination of the optical axis is 80° and the thickness of the sapphire substrate is approximately 35 μm.

[0063]

The optical compensation plate is arranged at a position where it can optically compensate a pre-tilt component on the incidence side, and the optical compensation plate is attached to the microlens array. After that, the quartz glass and the sapphire plate are ground and polished to a predetermined thickness. In

this case, the sapphire plate is ground and polished to a thickness of 12 μm, 16 μm, 20 μm, 24 μm and 28 μm.

[0064]

Then, an ITO film is formed on the cover glass by a sputtering technique, thus preparing a microlens board.

[0065]

In the liquid crystal panel, the microlens array is arranged on the incidence side, as in the above-described case. The liquid crystal panel is prepared, for example, in accordance with the following predetermined standard. Specifically, a liquid crystal cell of "XGA" standard having an effective pixel size (diagonal line) of 0.9 inches and a pixel pitch of 18 μm is prepared. Application of an orientation film, rubbing processing, and arrangement of a spacer are carried out at a rubbing angle of 90°, a twist angle of 90° and a cell gap of 3.2 μm, and liquid crystal ("MJ99200" (trade name) made by Merck Ltd.) is injected. The liquid crystal cell is thus completed.

[0066]

Moreover, an optical compensation plate is prepared by the process shown in Fig.9. The optical compensation plate is prepared so that the angle of inclination of the optical axis is 80° and the thickness of the sapphire substrate is approximately 30 μm.

[0067]

The optical compensation plate is arranged at a position where it can optically compensate a pre-tilt component on the emission side, and the optical compensation plate is attached to the emission-side dustproof glass made of quartz. After that, the quartz glass and the sapphire plate are ground and polished to a predetermined thickness equal to the thickness of the cover glass on the microlens array. In this case, the sapphire plate is ground and polished to a thickness of 12 μm, 16 μm, 20 μm, 24 μm and 28 μm.

[0068]

In this manner, the liquid crystal display device is completed as shown in Fig.5. Each optical compensation plate is arranged in such a manner that the angle of inclination of the optical axis of the optical compensation plate on the luminous flux incidence side is equal to the angle of inclination of the optical axis of the optical compensation plate on the luminous flux emission side. In this case, the angle of inclination of the optical axis of the optical compensation plate for compensating a pre-tilt component on the luminous flux incidence side need not be coincident with the angle of inclination of the optical axis of the optical compensation plate for compensating a pre-tilt component on the luminous flux emission side.

[0069]

Moreover, the flexible board 9 to be connected to the TFT board is attached and, for example, the metal frame 10 is fit thereon and the finishing plate 11 is

attached, as shown in Fig.12. The liquid crystal display device that can be used in the image display apparatus is thus completed.

[0070]

For the liquid crystal display device formed as described above, the lightness ratio and contrast ratio in the case of "white display" (without applying a voltage) of the image projected on the screen are measured in the case where the liquid crystal display devices have optical compensation plates and in the case where the liquid crystal display devices do not have optical compensation plates, using the optical system of the image display apparatus described with reference to Fig.13. In the image display apparatus that acquired the following results, the F-value of the image forming lens of the optical system is 2.3.

[0071]

Reference lightness is set in the case where the sapphire plate has a thickness of 20 μm. Not only the thickness of the sapphire plate but also the relation between the sum of the air lengths (optical path lengths) in the resin-thickness part and the sapphire plate and the lightness in the case of "white display" (without applying a voltage) are measured, as shown in Fig.18. The air length (optical path length) is calculated by multiplying the thickness of a certain medium by its refractive index. In this case, the size of the image projected on the screen is set to be 40 inches in diagonal.

[0072]

The results of the measurement show that in a liquid crystal panel having a pixel pitch of 14 μm and a diagonal line of 0.7 inches, when the sum of the air lengths of the resin and sapphire is approximately 18 μm, the lightness of white in "white display" (without applying a voltage) is almost at the maximum value and the maximum contrast is achieved, as shown in Fig.19. By thus optimizing the conditions, it is possible to simultaneously achieve higher luminance and higher contrast of the displayed image.

[0073]

[Preparation of Liquid Crystal Display Device (4)]

First, as in the case described with reference to Fig.15, spherical surfaces each having a diameter substantially equal to the pixel size are formed at a spacing (between the centers of the spherical surfaces) equal to the pixel pitch, on a quarts substrate having a thickness of 1.5 mm. Then, a resin having a refractive index of 1.60 is applied and extended by a spin coat technique, as shown in Fig.17. In this case, the number of rotations and the rotation time are optimized so that the thickness shown as "resin thickness" in Fig.17 becomes 3 μm. Then, as a cover glass, an optical compensation plate having a thickness greater than a predetermined thickness is prepared by the process shown in Fig.9. The optical compensation plate is prepared so that the angle of inclination of the optical axis is 80° and the thickness of the sapphire substrate is approximately 35 μm.

[0074]

The optical compensation plate is arranged at a position where it can optically compensate a pre-tilt component on the incidence side, and the optical compensation plate is attached to the microlens array. After that, the quartz glass and the sapphire plate are ground and polished to a predetermined thickness. In this case, the sapphire plate is ground and polished to a thickness of 12 μm, 16 μm, 20 μm, 24 μm and 28 μm.

[0075]

Then, an ITO film is formed on the cover glass by a sputtering technique, thus preparing a microlens board.

[0076]

In the liquid crystal panel, the microlens array is arranged on the incidence side, as in the above-described case. The liquid crystal panel is prepared, for example, in accordance with the following predetermined standard. Specifically, a liquid crystal cell of "XGA" standard having an effective pixel size (diagonal line) of 0.9 inches and a pixel pitch of 18 μm is prepared. Application of an orientation film, rubbing processing, and arrangement of a spacer are carried out at a rubbing angle of 90°, a twist angle of 90° and a cell gap of 3.2 μm, and liquid crystal ("MJ99200" (trade name) made by Merck Ltd.) is injected. The liquid crystal cell is thus completed.

[0077]

Moreover, an optical compensation plate is prepared by the process shown in

Fig.9. The optical compensation plate is prepared is prepared so that the angle of inclination of the optical axis is 80° and the thickness of the sapphire substrate is approximately 30 μm.

[0078]

The optical compensation plate is arranged at a position where it can optically compensate a pre-tilt component on the emission side, and the optical compensation plate is attached to the emission-side dustproof glass made of quartz. After that, the quartz glass and the sapphire plate are ground and polished to a predetermined thickness equal to the thickness of the cover glass on the microlens array. In this case, the sapphire plate is ground and polished to a thickness of 12 μm, 16 μm, 20 μm, 24 μm and 28 μm.

[0079]

In this manner, the liquid crystal display device is completed as shown in Fig.5. Each optical compensation plate is arranged in such a manner that the angle of inclination of the optical axis of the optical compensation plate on the luminous flux incidence side is equal to the angle of inclination of the optical axis of the optical compensation plate on the luminous flux emission side. In this case, the angle of inclination of the optical axis of the optical compensation plate for compensating a pre-tilt component on the luminous flux incidence side need not be coincident with the angle of inclination of the optical axis of the optical compensation plate for compensating a pre-tilt component on the luminous flux

emission side.

[0080]

Moreover, the flexible board 9 to be connected to the TFT board is attached and, for example, the metal frame 10 is fit thereon and the finishing plate 11 is attached, as shown in Fig.12. The liquid crystal display device that can be used in the image display apparatus is thus completed.

[0081]

For the liquid crystal display device formed as described above, the lightness ratio and contrast ratio in the case of "white display" (without applying a voltage) of the image projected on the screen are measured in the case where the liquid crystal display devices have optical compensation plates and in the case where the liquid crystal display devices do not have optical compensation plates, using the optical system of the image display apparatus described with reference to Fig.13. In the image display apparatus that acquired the following results, the F-value of the image forming lens of the optical system is 2.3.

[0082]

Reference lightness is set in the case where the sapphire plate has a thickness of 20 μm. Not only the thickness of the sapphire plate but also the relation between the sum of the air lengths (optical path lengths) in the resin-thickness part and the sapphire plate and the lightness in the case of "white display" (without applying a voltage) are measured, as shown in Fig.18. The air length (optical path

length) is calculated by multiplying the thickness of a certain medium by its refractive index. In this case, the size of the image projected on the screen is set to be 40 inches in diagonal.

[0083]

The results of the measurement show that in a liquid crystal panel having a pixel pitch of 11 μm and a diagonal line of 0.55 inches, when the sum of the air lengths of the resin and sapphire is approximately 13 μm, the lightness of white in "white display" (without applying a voltage) is almost at the maximum value and the maximum contrast is achieved, as shown in Fig.20. By thus optimizing the conditions, it is possible to simultaneously achieve higher luminance and higher contrast of the displayed image.

[0084]

[Advantages/Effects of the Invention]

As described above, in the liquid crystal display device according to this invention, in the case where such liquid crystal display device is used as a spatial light modulator in image display device, higher luminance of a displayed image can be realized by the microlens array and the influence of a pre-tilt of liquid crystal molecules in the liquid crystal panel is optically compensated by the optical compensation layer. Higher contrast of the displayed image and a longer life time of the apparatus are thus realized.

[0085]

Further, since inorganic material having highly light resistance is used as the optical compensation layer, it is possible to realize high luminance of displayed image due to realization of large output of the light source of the image display apparatus. Moreover, since the optical compensation layer is disposed along the liquid crystal panel surface, there is no possibility that the structure of the apparatus may become large. Further, by using sapphire or crystal having high thermal conductivity as inorganic material. It is also possible to suppress elevation of temperature of the liquid crystal panel.

[0086]

Moreover, in the image display apparatus according to this invention, higher luminance of a displayed image can be realized by the microlens array provided in the liquid crystal display device and the influence due to a pre-tilt of liquid crystal molecules in the liquid crystal panel is optically compensated by the optical compensation layer, thus realizing higher contrast of the displayed image. Moreover, long life time can be realized. Since a highly light-resistant inorganic material is used as the optical compensation layer, higher luminance of the displayed image can be realized by large output of the light source of the image display apparatus. Since the optical compensation layer is arranged along the liquid crystal panel surface, there is no possibility that the size of the apparatus may be increased. Moreover, if sapphire or crystal, which is highly thermally conductive, is used as the inorganic material, rise in the temperature of the liquid

crystal display device can be suppressed.

[0087]

Namely, this invention makes it possible to provide liquid crystal display device in which in the case where such liquid crystal device is used as a spatial light modulator in image display apparatus, there is no possibility that the structure of the image display apparatus may become large, and high contrast can be realized while maintaining sufficient long life time; and makes it possible to provide image display apparatus caused to be of the configuration in which such liquid crystal display device is used.

[Brief Description of the Drawings]

Fig. 1 is a side view showing a structure of a liquid crystal device.

Fig. 2 is a sectional view showing the structure of the liquid crystal display device.

Fig. 3 is a graph showing transmittance ratio in the liquid crystal display device.

Fig. 4 is a graph showing transmittance ratio in the case where the order of optical compensation plates is changed in the liquid crystal display device.

Fig. 5 is a side view showing another exemplary structure of the liquid crystal display device.

Fig. 6 is a graph showing transmittance ratio in the case where the thickness of an optical compensation plate is changed in the liquid crystal display device.

Fig. 7 is a side view showing the relation between the optical axis of the optical compensation plate in the liquid crystal display device and the optical axis of a liquid crystal panel (in the case where Δn has different signs).

Fig. 8 is a side view showing the relation between the optical axis of the optical compensation plate in the liquid crystal display device and the optical axis of the liquid crystal panel (in the case where Δn has the same sign).

Fig. 9 is a flowchart showing a process of preparing the optical compensation pate of the liquid crystal display device.

Fig. 10 is a perspective view showing the process of preparing the optical compensation plate of the liquid crystal display device.

Fig. 11 is a perspective view showing arrangement states of optical compensation plate of the liquid crystal display device.

Fig. 12 is a perspective view showing the appearance of the liquid crystal display device.

Fig. 13 is a plan view showing the structure of an image display apparatus according to this invention.

Fig. 14 is a graph showing the effects of the optical compensation plate of the liquid crystal display device in the image display apparatus.

Fig. 15 is a longitudinal sectional view showing a process of preparing a microlens array in the liquid crystal device.

Fig. 16 is a graph showing the effects of the optical compensation plate

(provided over the microolens array) of the liquid crystal display device in the image display apparatus.

Fig. 17 is a longitudinal section view showing a structure of the microlens array in the liquid crystal display device.

Fig. 18 is a longitudinal sectional view showing a structure in which the optical compensation plate is provided over the microlens array in the liquid crystal display device.

Fig. 19 is a graph showing the effects of the optical compensation plate of the liquid crystal display device in the image display apparatus (with a 14-μm pixel pitch and 0.7-inch panel)

Fig. 20 is a graph showing the effects of the optical compensation plate of the liquid crystal display device in the image display apparatus (with a 11-μm pixel and 0.55-inch panel)

[Explanation of Referenced Numbers]

1

Incidence Side Dustproof Glass

2

Microlens Board

4, 6

Optical Compensation Plate

5

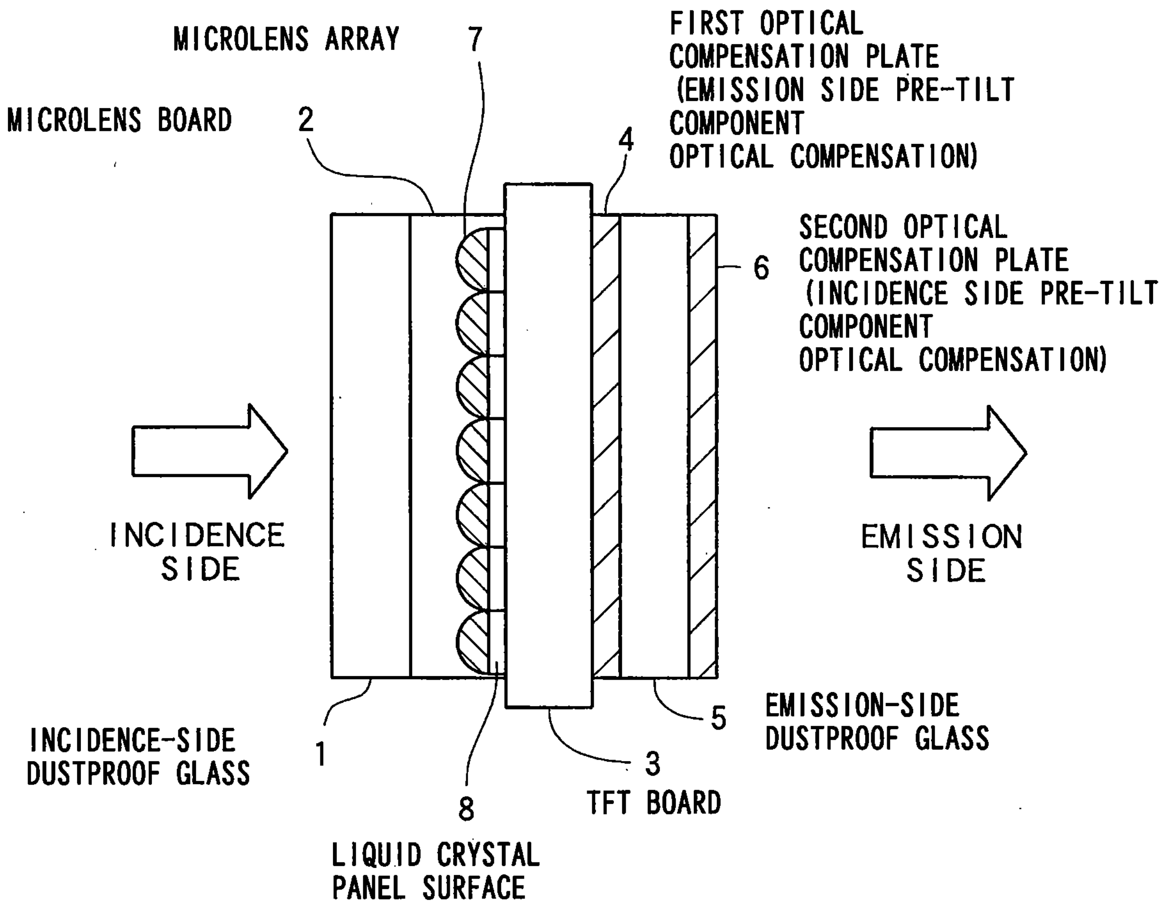
Emission Side Dustproof Glass

8

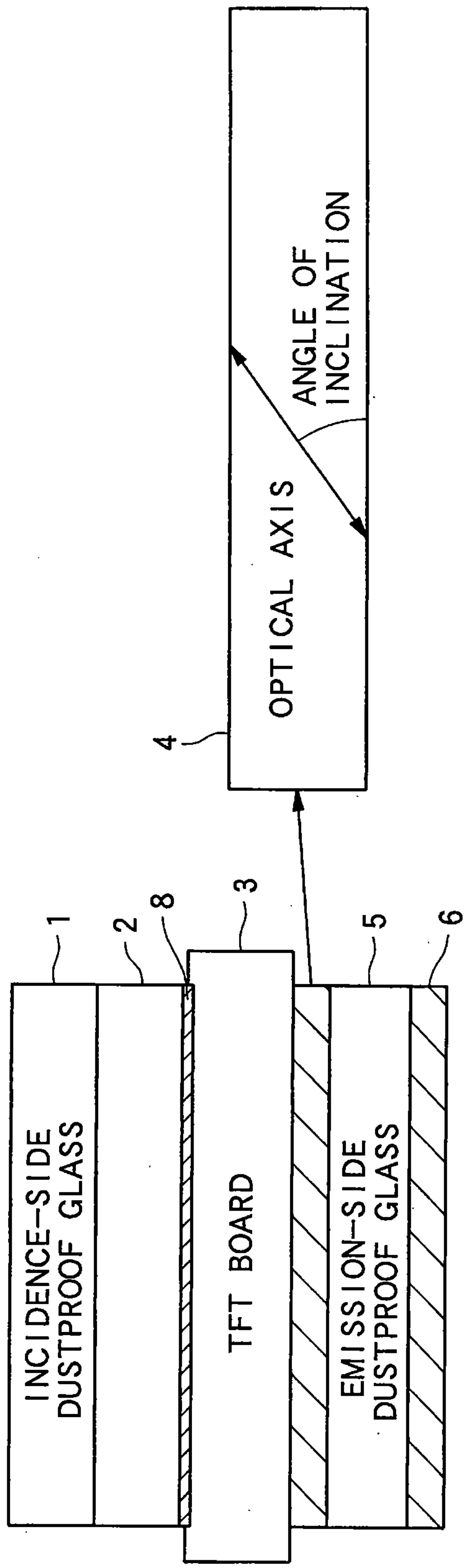
Liquid Crystal Panel Surface

[DOCUMENT NAME] DRAWING

[FIG.1]



[FIG.2]



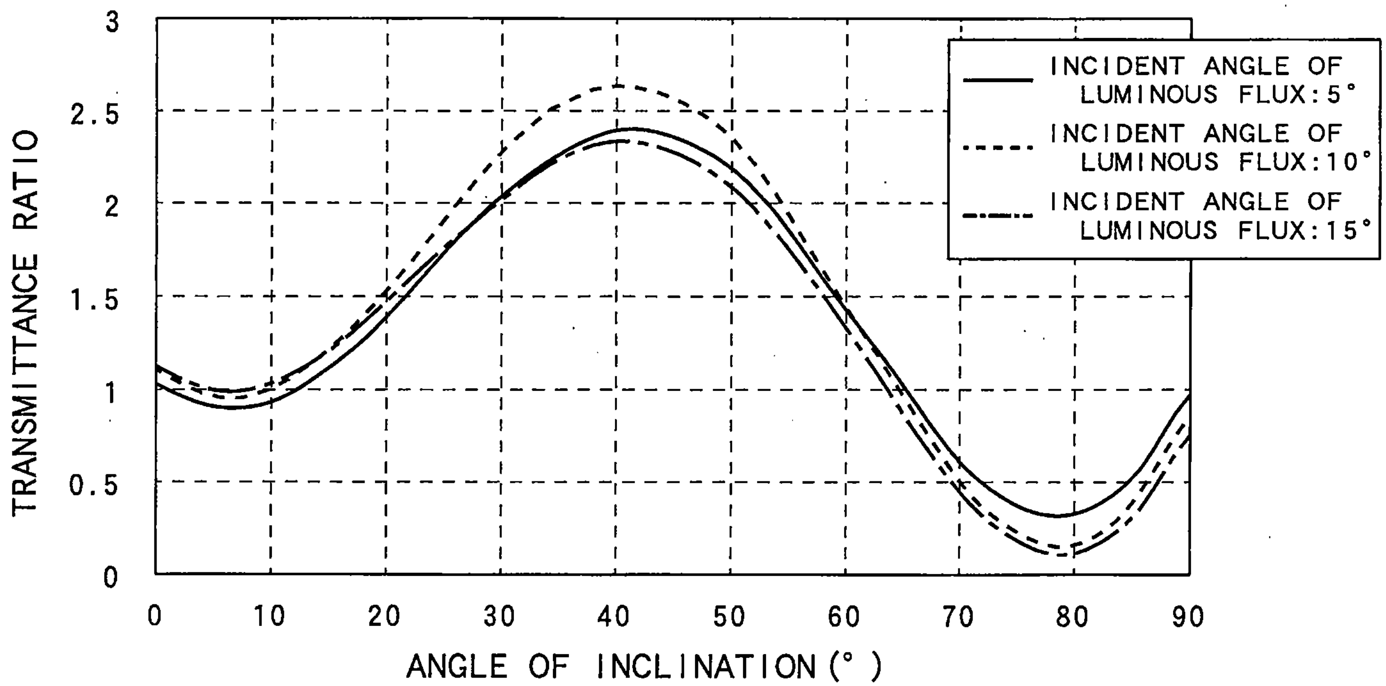
INCIDENCE-SIDE DUSTPROOF GLASS
TFT BOARD
EMISSION-SIDE DUSTPROOF GLASS
OPTICAL AXIS
ANGLE OF INCLINATION
1
2
8
3
5
6
4

[FIG.3]

TRANSMITTANCE RATIO=(TRANSMITTANCE IN THE CASE WHERE OPTICAL COMPENATION PLATE IS ARRANGED)/(TRNASMITTANCE IN THE CASE WHERE OPTICAL COMPENSATION PLATE IS NOT ARRANGED)

TRANSMITTANCE RATIO<1:TRANSMITTANCE OF BLACK IS REDUCED BY ARRANGEMENT OF OPTICAL COMPENSATION PLATE

TRANSMITTANCE RATIO>1:TRANSMITTANCE OF BLACK IS INCREASED BY ARRANGEMENT OF OPTICAL COMPENSATION PLATE

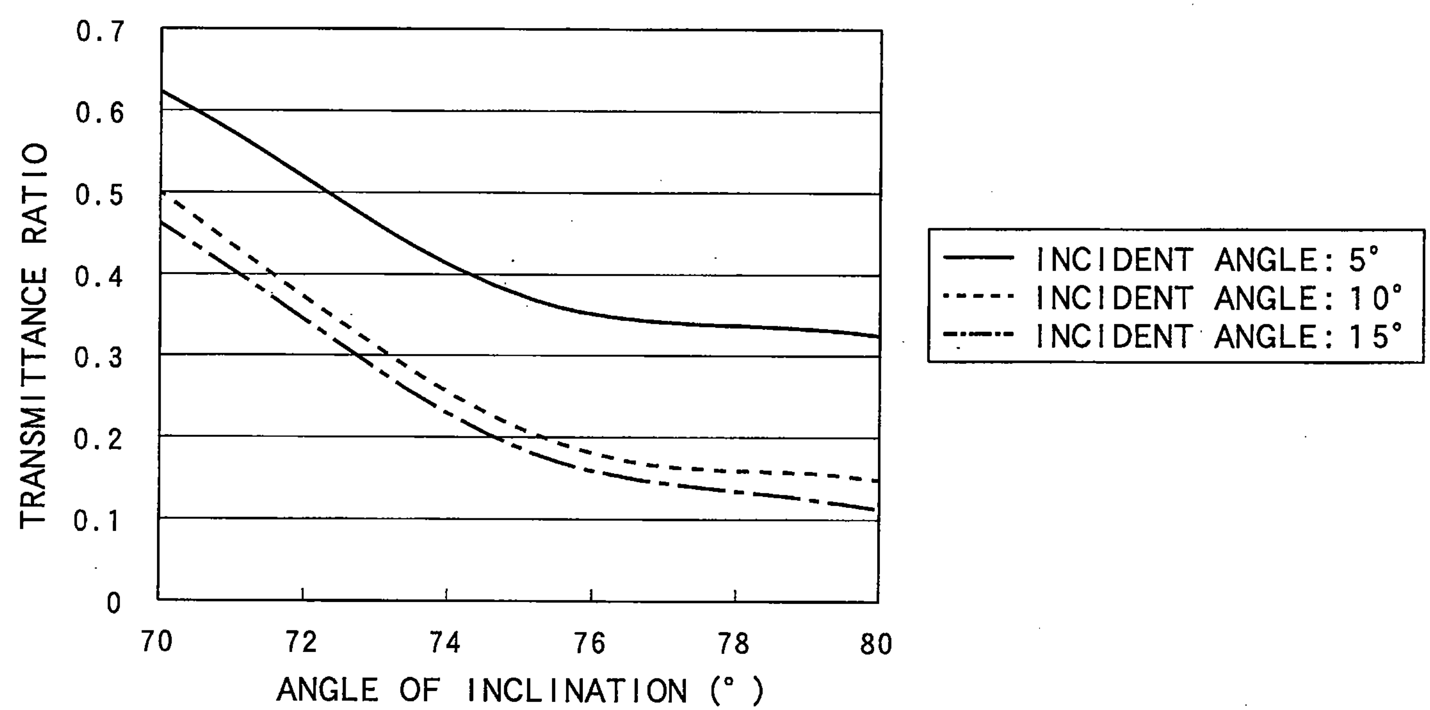


[FIG.4]

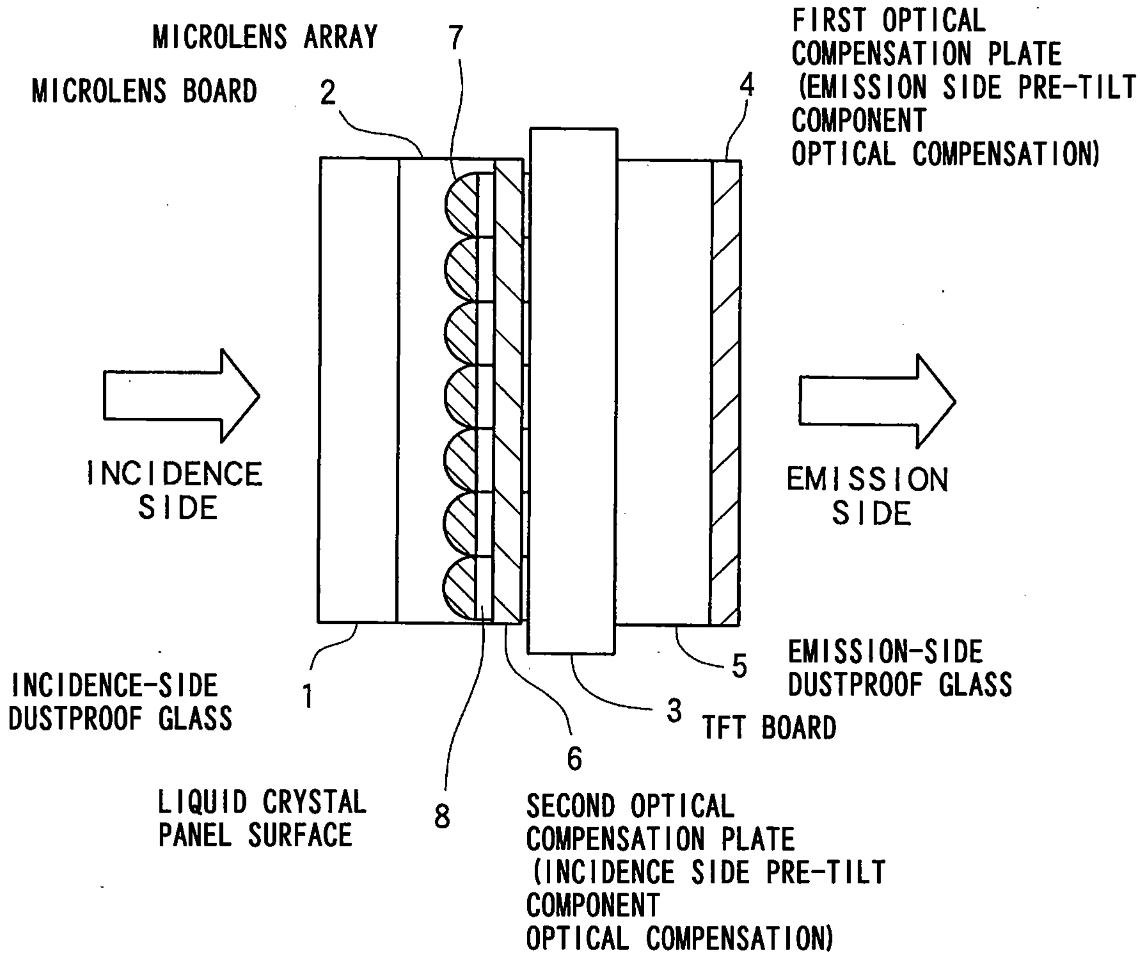
TRANSMITTANCE RATIO = (TRANSMITTANCE IN THE CASE WHERE OPTICAL COMPENATION PLATE IS ARRANGED)/(TRNASMITTANCE IN THE CASE WHERE OPTICAL COMPENSATION PLATE IS NOT ARRANGED)

TRANSMITTANCE RATIO < 1: TRANSMITTANCE OF BLACK IS REDUCED BY ARRANGEMENT OF OPTICAL COMPENSATION PLATE

TRANSMITTANCE RATIO > 1: TRANSMITTANCE OF BLACK IS INCREASED BY ARRANGEMENT OF OPTICAL COMPENSATION PLATE



[FIG.5]

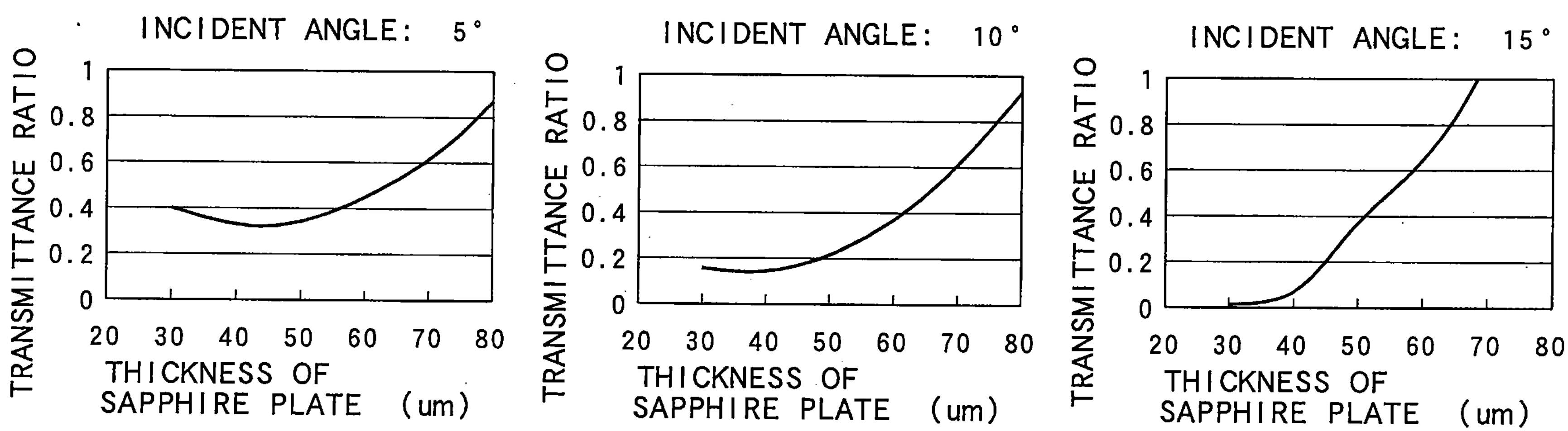

MICROLENS ARRAY
7
MICROLENS BOARD
2
FIRST OPTICAL
COMPENSATION PLATE
(EMISSION SIDE PRE-TILT
COMPONENT
OPTICAL COMPENSATION)
4
INCIDENCE
SIDE
EMISSION
SIDE
INCIDENCE-SIDE
DUSTPROOF GLASS
1
5
EMISSION-SIDE
DUSTPROOF GLASS
3
TFT BOARD
6
LIQUID CRYSTAL
PANEL SURFACE
8
SECOND OPTICAL
COMPENSATION PLATE
(INCIDENCE SIDE PRE-TILT
COMPONENT
OPTICAL COMPENSATION)

[FIG.6]

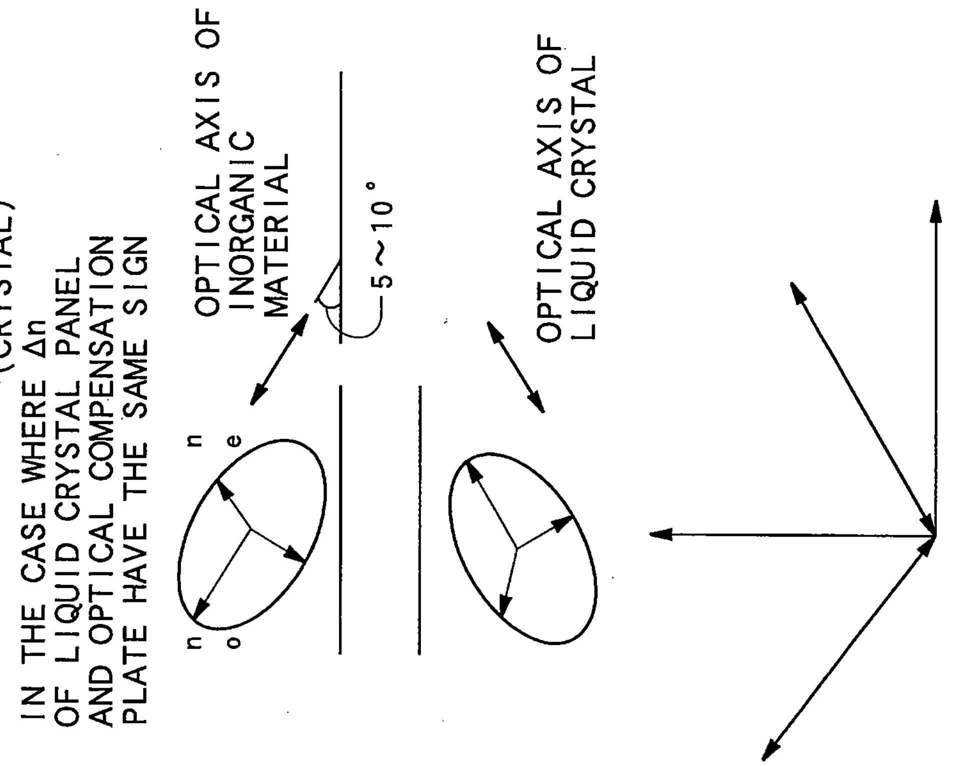
TRANSMITTANCE RATIO=(TRANSMITTANCE IN THE CASE WHERE OPTICAL COMPENATION PLATE IS ARRANGED)/(TRNASMITTANCE IN THE CASE WHERE OPTICAL COMPENSATION PLATE IS NOT ARRANGED)

TRANSMITTANCE RATIO<1:TRANSMITTANCE OF BLACK IS REDUCED BY ARRANGEMENT OF OPTICAL COMPENSATION PLATE

TRANSMITTANCE RATIO>1:TRANSMITTANCE OF BLACK IS INCREASED BY ARRANGEMENT OF OPTICAL COMPENSATION PLATE

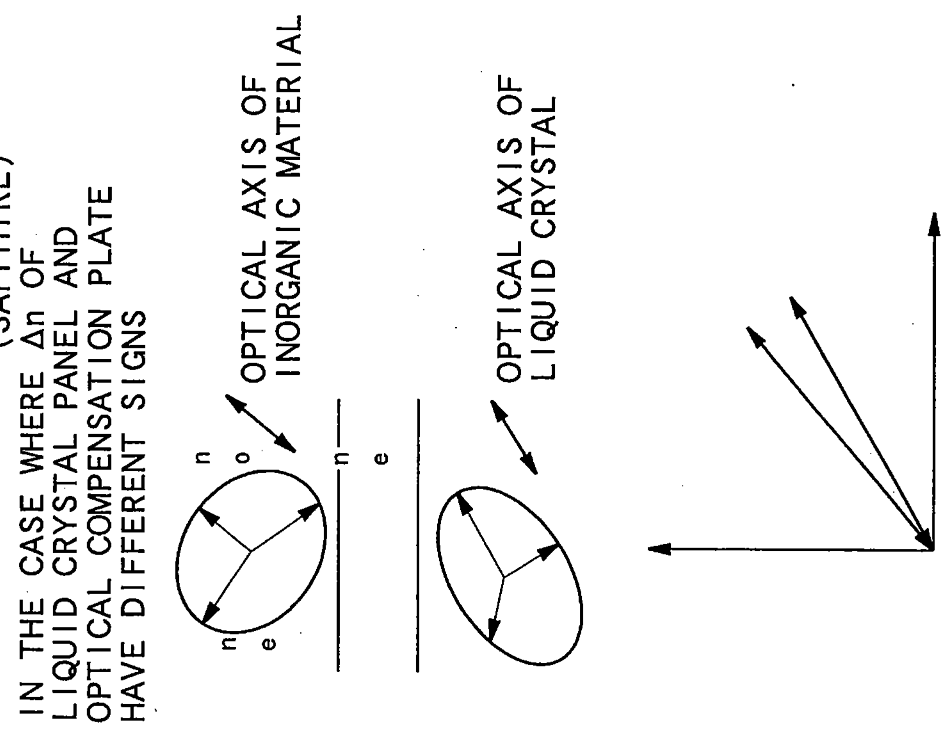


[FIG.7]



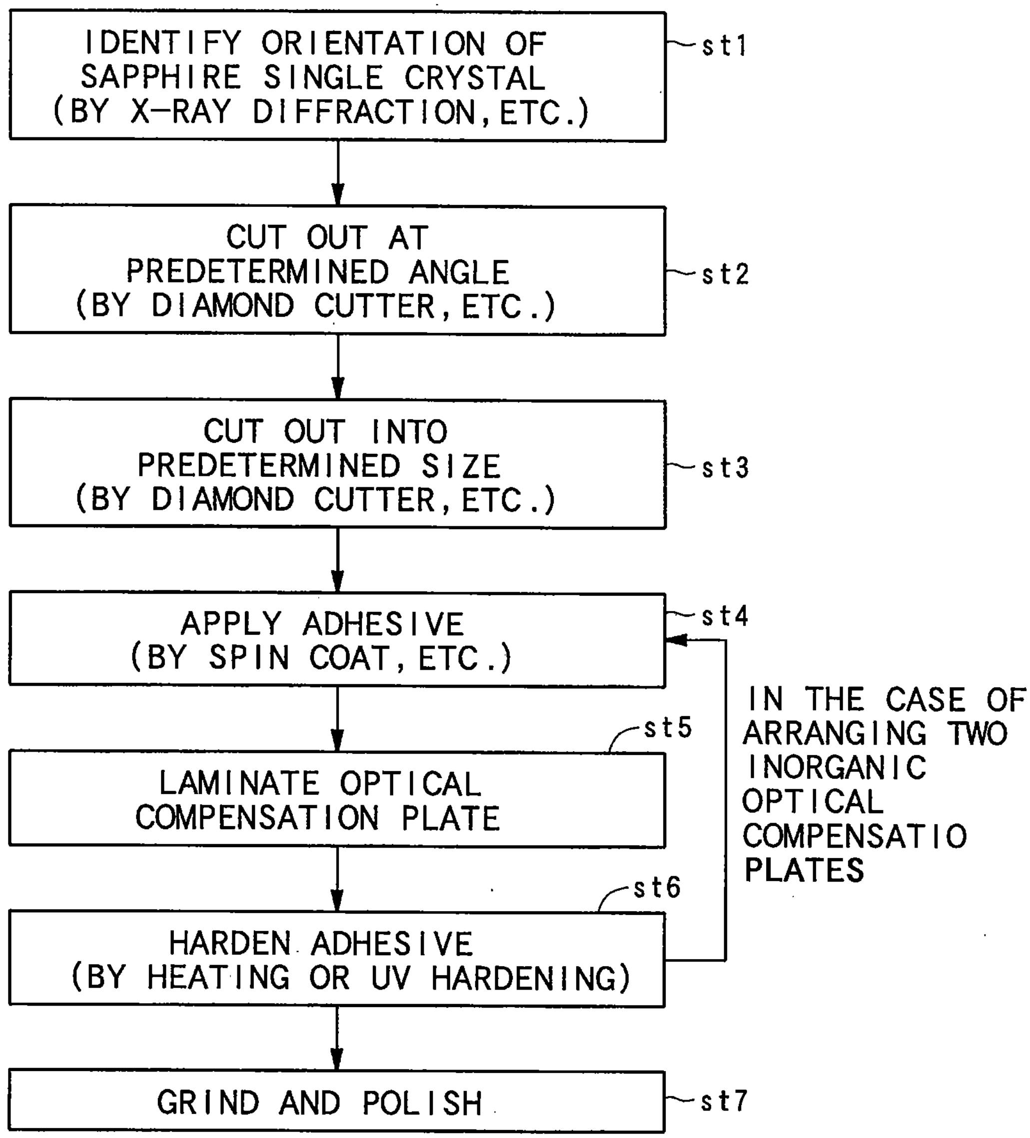
IN THE CASE WHERE Δn OF LIQUID CRYSTAL PANEL AND OPTICAL COMPENSATION PLATE HAVE THE SAME SIGN
(CRYSTAL)
OPTICAL AXIS OF INORGANIC MATERIAL
5～10°
OPTICAL AXIS OF LIQUID CRYSTAL
ne
no

[FIG.8]

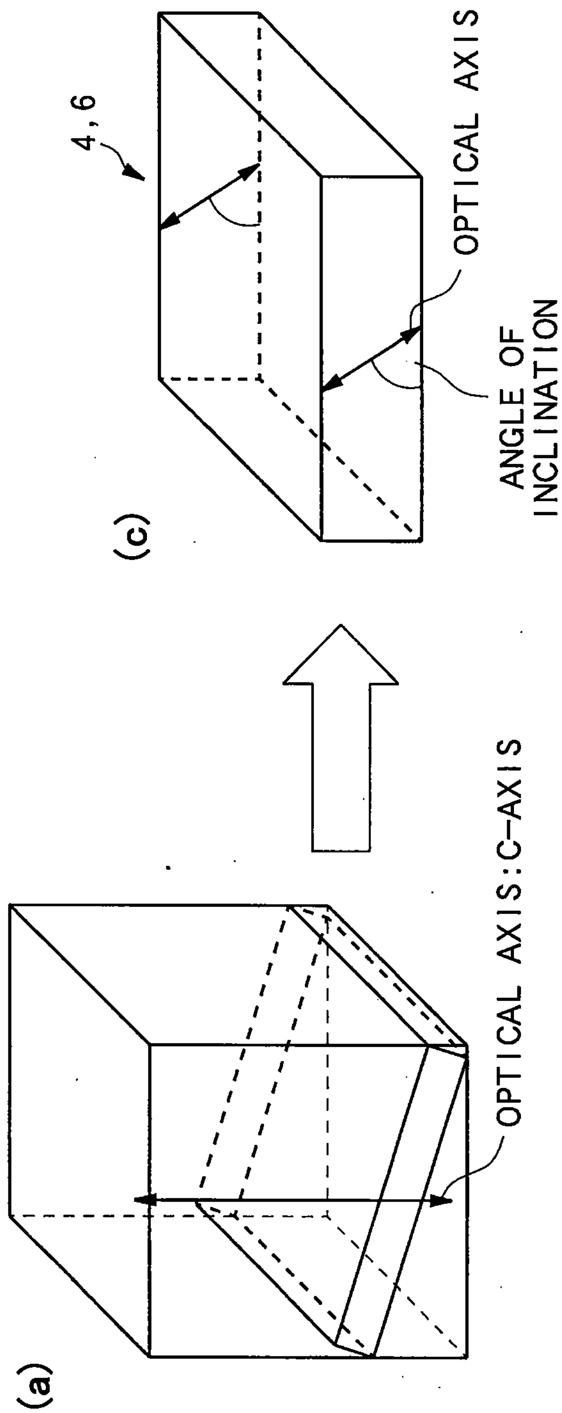


IN THE CASE WHERE Δn OF LIQUID CRYSTAL PANEL AND OPTICAL COMPENSATION PLATE HAVE DIFFERENT SIGNS
(SAPPHIRE)
OPTICAL AXIS OF INORGANIC MATERIAL
OPTICAL AXIS OF LIQUID CRYSTAL
no
ne
n
e

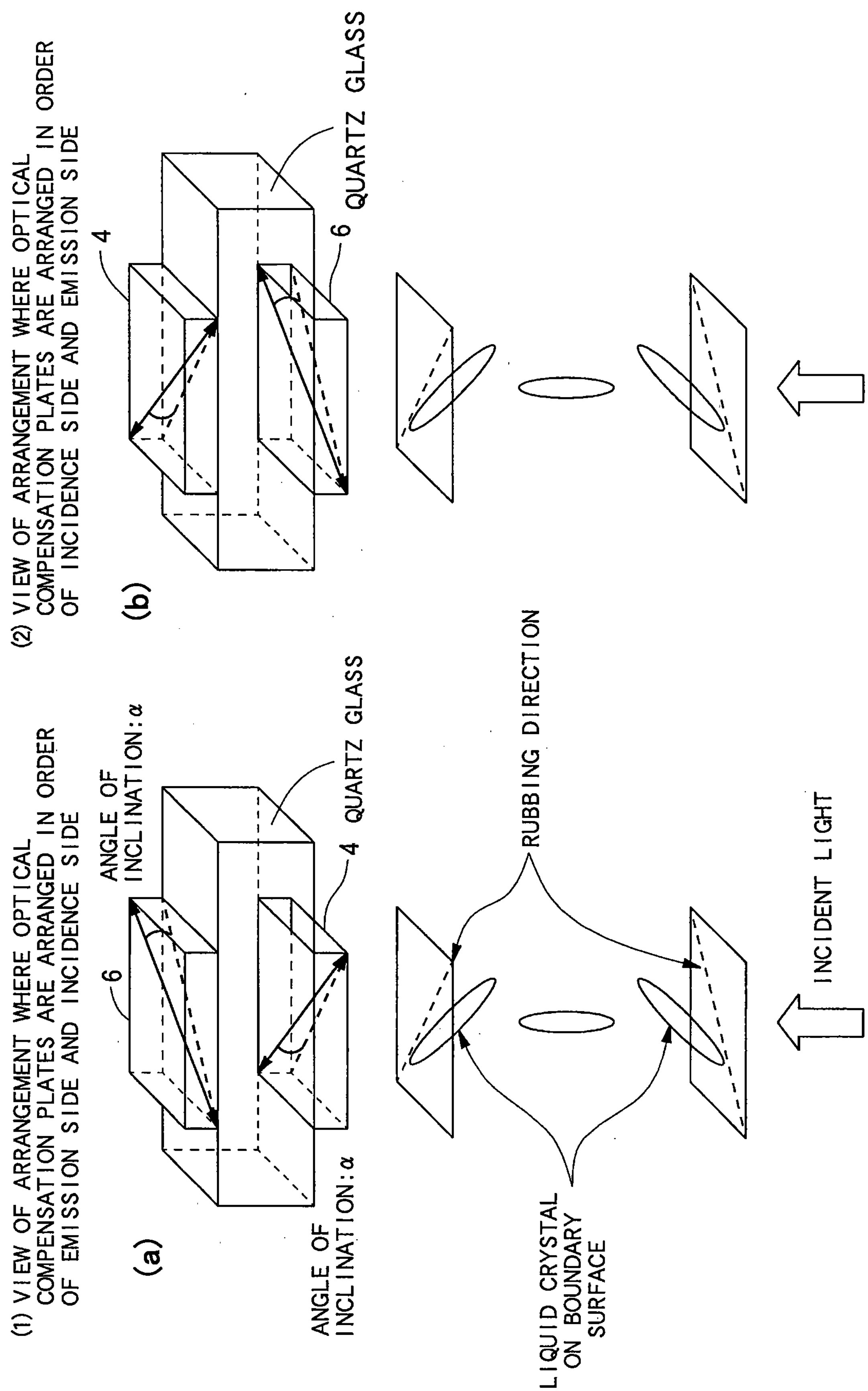
[FIG.9]


IDENTIFY ORIENTATION OF SAPPHIRE SINGLE CRYSTAL (BY X-RAY DIFFRACTION, ETC.)
st1
CUT OUT AT PREDETERMINED ANGLE (BY DIAMOND CUTTER, ETC.)
st2
CUT OUT INTO PREDETERMINED SIZE (BY DIAMOND CUTTER, ETC.)
st3
APPLY ADHESIVE (BY SPIN COAT, ETC.)
st4
LAMINATE OPTICAL COMPENSATION PLATE
st5
HARDEN ADHESIVE (BY HEATING OR UV HARDENING)
st6
GRIND AND POLISH
st7
IN THE CASE OF ARRANGING TWO INORGANIC OPTICAL COMPENSATIO PLATES

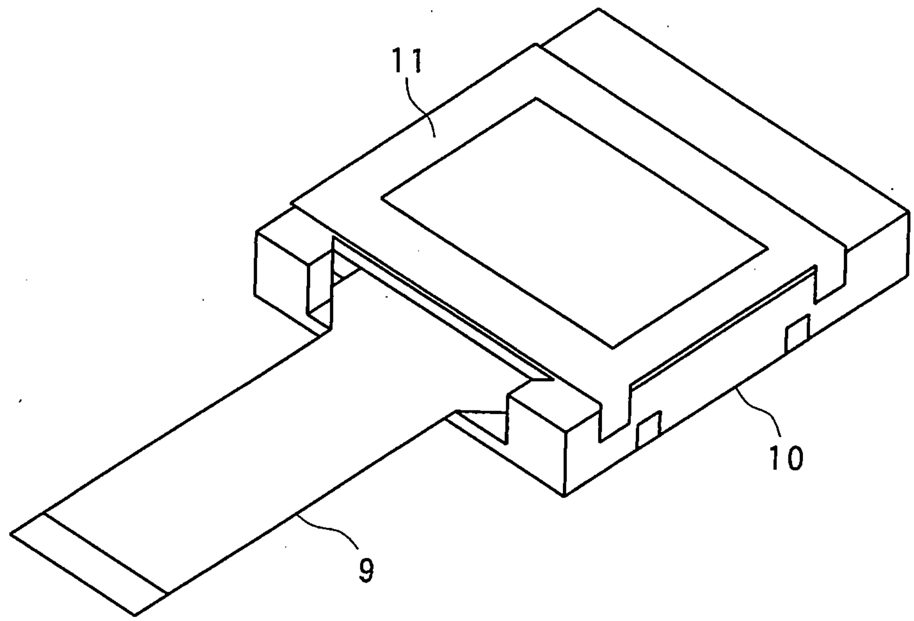
[FIG.10]


(a)
OPTICAL AXIS:C-AXIS
(b)
C-AXIS
a1
a2
a3
(c)
4,6
OPTICAL AXIS
ANGLE OF
INCLINATION

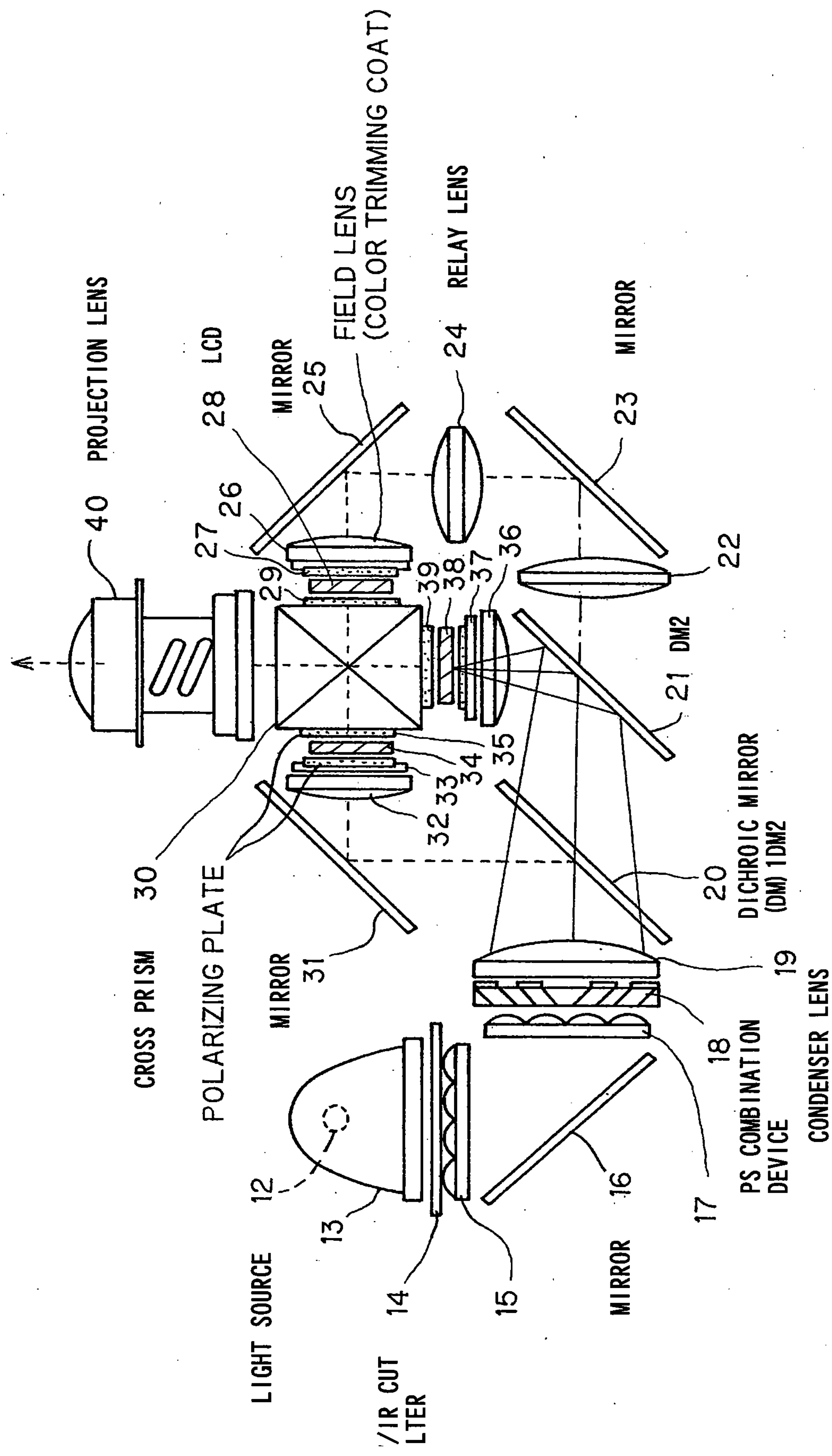
[FIG.11]


(1) VIEW OF ARRANGEMENT WHERE OPTICAL COMPENSATION PLATES ARE ARRANGED IN ORDER OF EMISSION SIDE AND INCIDENCE SIDE
(a)
ANGLE OF INCLINATION:α
ANGLE OF INCLINATION:α
6
4
QUARTZ GLASS
(2) VIEW OF ARRANGEMENT WHERE OPTICAL COMPENSATION PLATES ARE ARRANGED IN ORDER OF INCIDENCE SIDE AND EMISSION SIDE
(b)
4
6
QUARTZ GLASS
RUBBING DIRECTION
LIQUID CRYSTAL ON BOUNDARY SURFACE
INCIDENT LIGHT

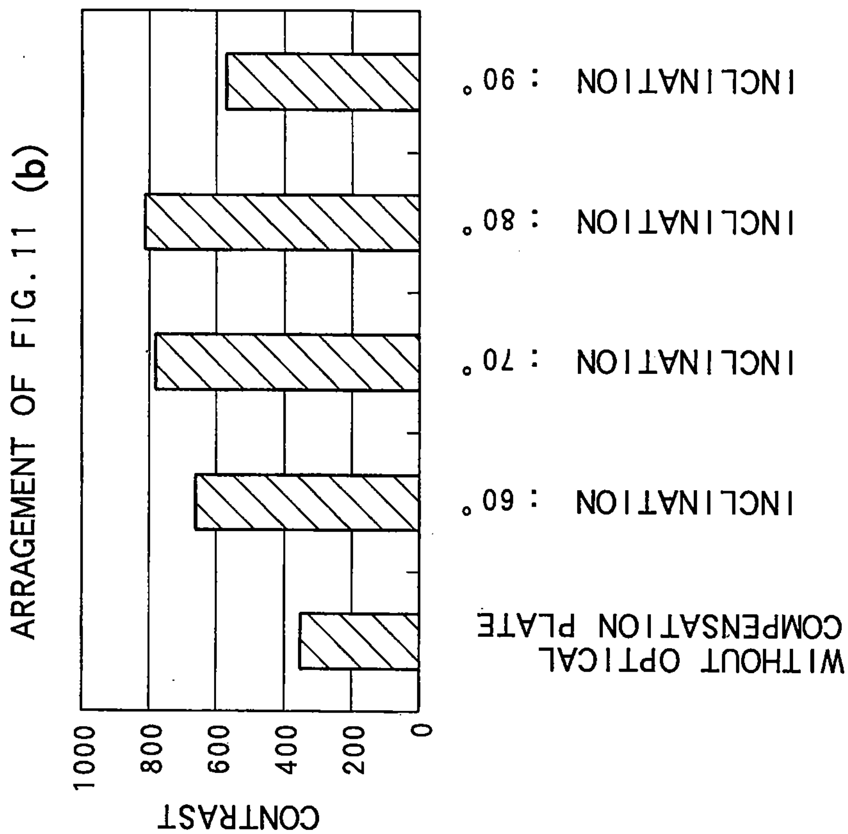
[FIG.12]

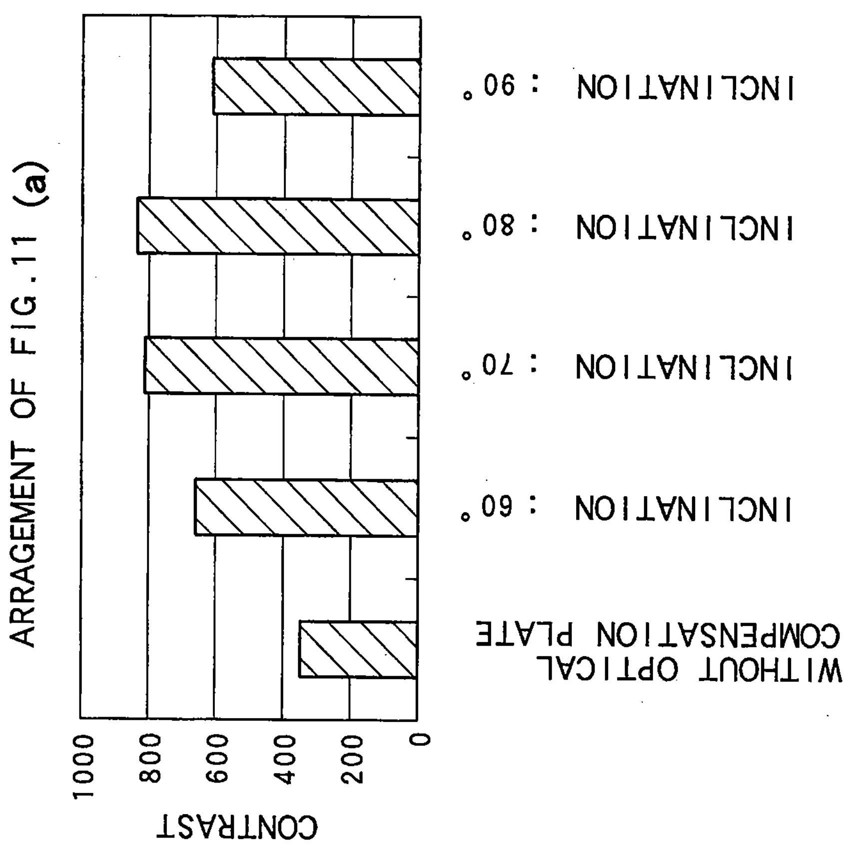


[FIG.13]

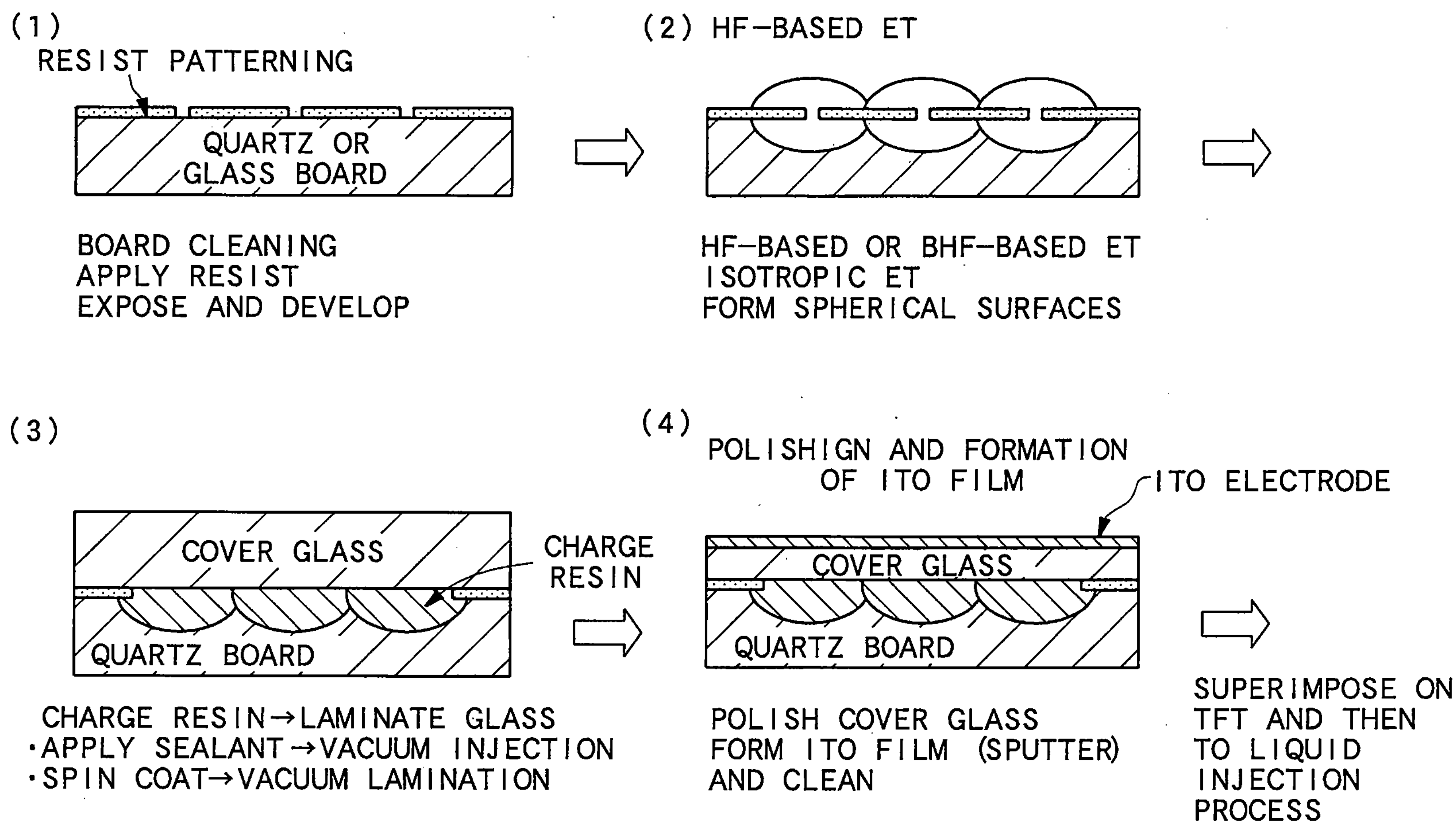

PROJECTION LENS
40
CROSS PRISM
30
POLARIZING PLATE
MIRROR
31
28 LCD
MIRROR
25
FIELD LENS
(COLOR TRIMMING COAT)
RELAY LENS
24
MIRROR
23
22
26
27
29
39
38
37
36
35
34
33
32
21 DM2
DICHROIC MIRROR
(DM) 1DM2
20
19
CONDENSER LENS
PS COMBINATION
DEVICE
18
17
MIRROR
16
15
14
13
12
LIGHT SOURCE
/IR CUT
LTER

[FIG.14]


ARRAGEMENT OF FIG.11 (b)
CONTRAST
0
200
400
600
800
1000
WITHOUT OPTICAL COMPENSATION PLATE
INCLINATION : 60°
INCLINATION : 70°
INCLINATION : 80°
INCLINATION : 90°

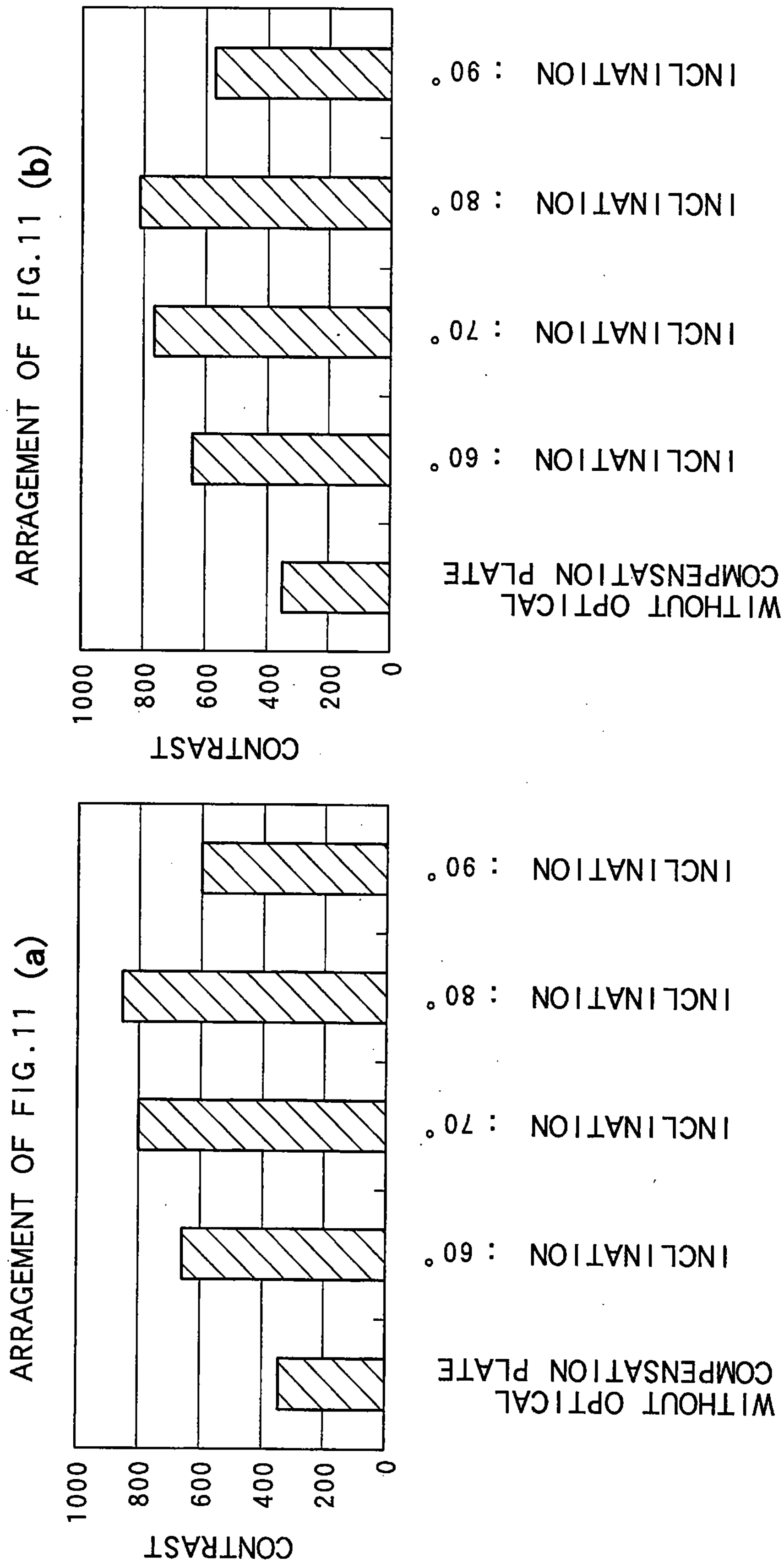

ARRAGEMENT OF FIG.11 (a)
CONTRAST
0
200
400
600
800
1000
WITHOUT OPTICAL COMPENSATION PLATE
INCLINATION : 60°
INCLINATION : 70°
INCLINATION : 80°
INCLINATION : 90°

[FIG.15]

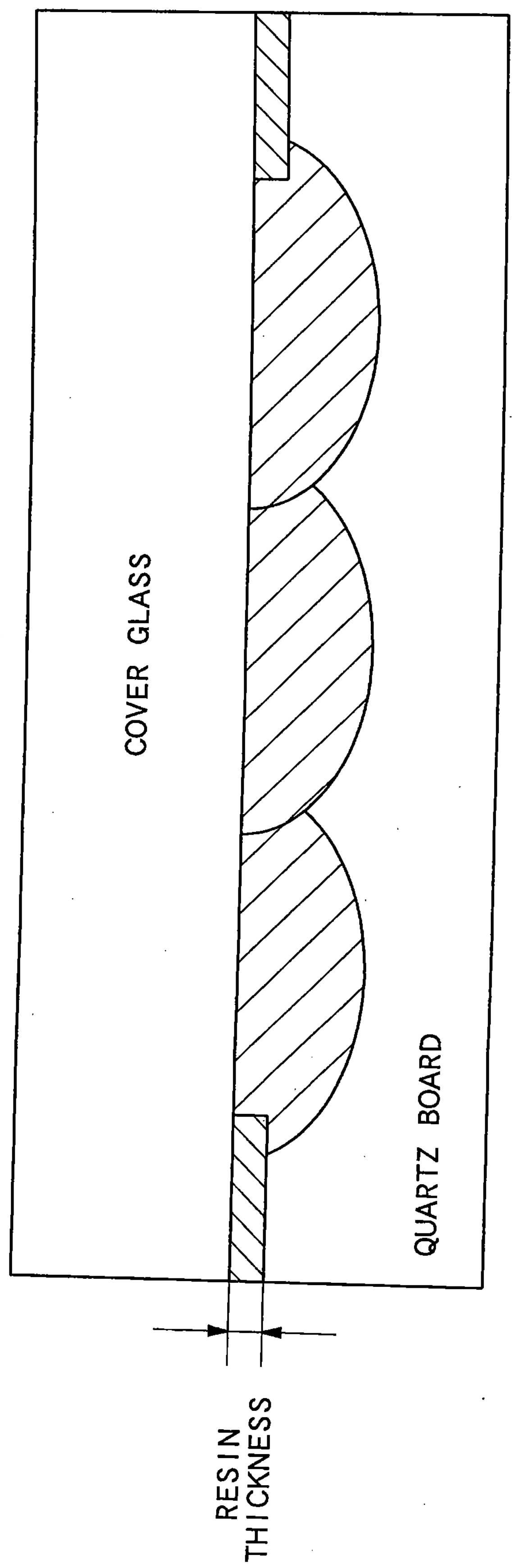


(1)
RESIST PATTERNING
QUARTZ OR
GLASS BOARD
BOARD CLEANING
APPLY RESIST
EXPOSE AND DEVELOP
(2) HF-BASED ET
HF-BASED OR BHF-BASED ET
ISOTROPIC ET
FORM SPHERICAL SURFACES
(3)
COVER GLASS
CHARGE
RESIN
QUARTZ BOARD
CHARGE RESIN→LAMINATE GLASS
·APPLY SEALANT→VACUUM INJECTION
·SPIN COAT→VACUUM LAMINATION
(4)
POLISHIGN AND FORMATION
OF ITO FILM
ITO ELECTRODE
COVER GLASS
QUARTZ BOARD
POLISH COVER GLASS
FORM ITO FILM (SPUTTER)
AND CLEAN
SUPERIMPOSE ON
TFT AND THEN
TO LIQUID
INJECTION
PROCESS

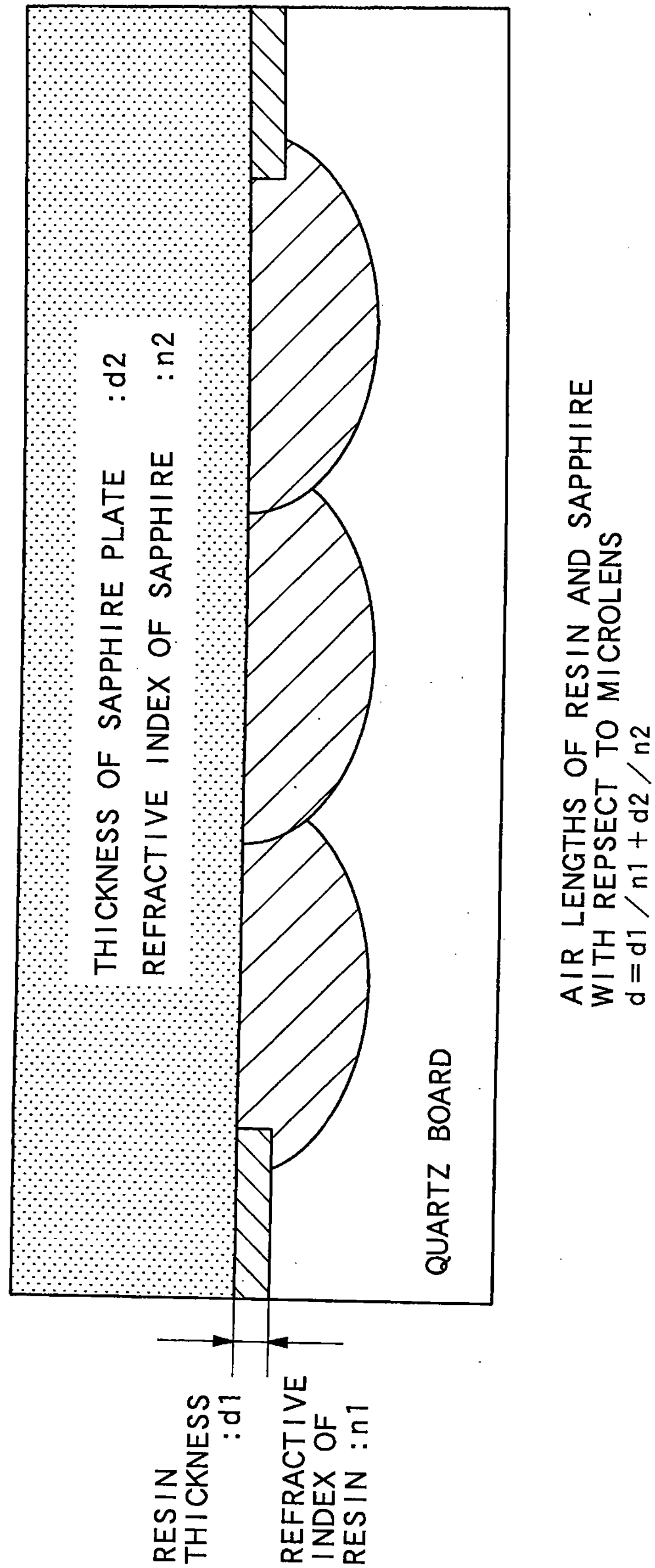
[FIG.16]


ARRAGEMENT OF FIG.11 (b)
CONTRAST
1000
800
600
400
200
0
WITHOUT OPTICAL COMPENSATION PLATE
INCLINATION : 60°
INCLINATION : 70°
INCLINATION : 80°
INCLINATION : 90°
ARRAGEMENT OF FIG.11 (a)
CONTRAST
1000
800
600
400
200
0
WITHOUT OPTICAL COMPENSATION PLATE
INCLINATION : 60°
INCLINATION : 70°
INCLINATION : 80°
INCLINATION : 90°

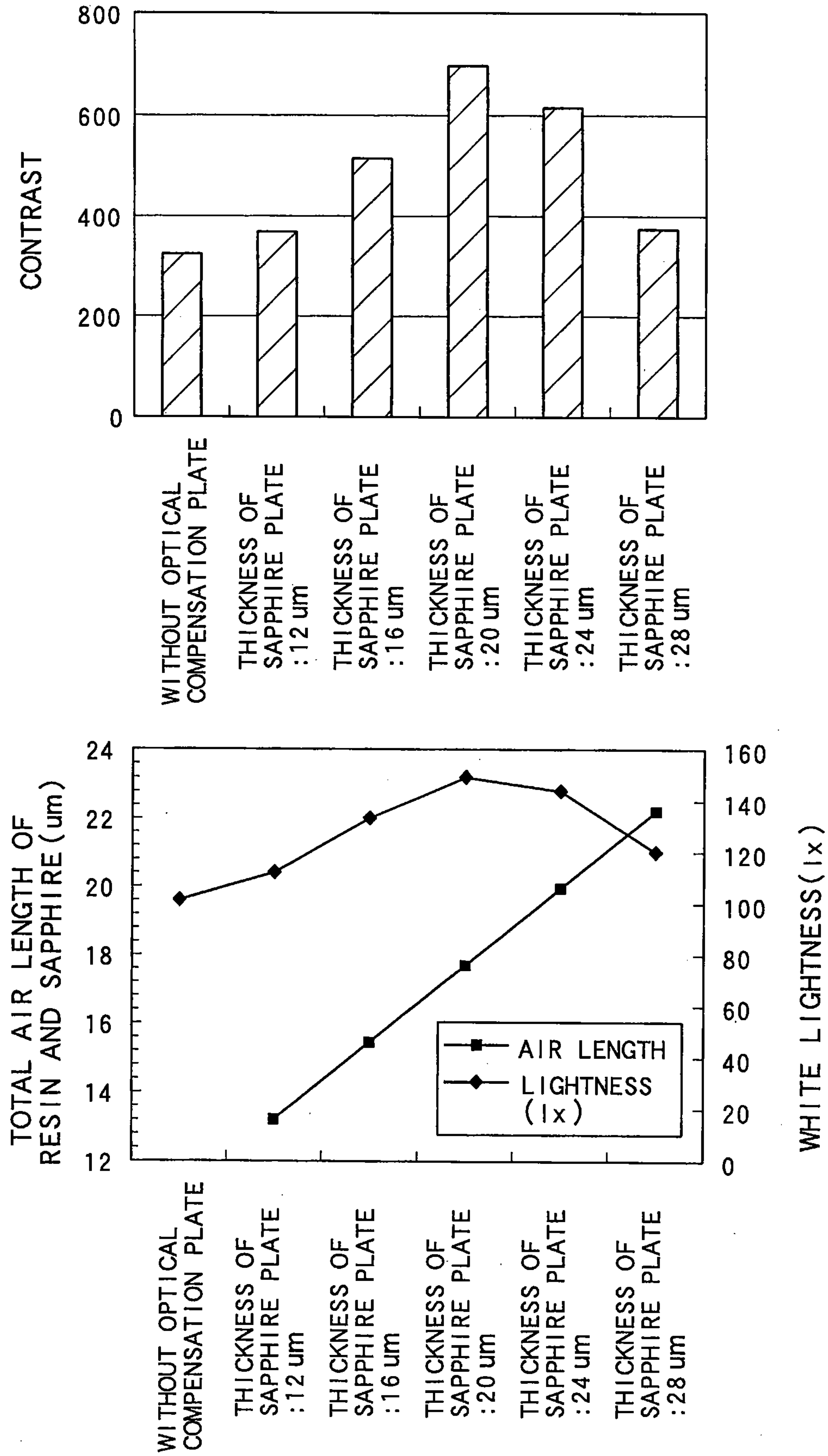
[FIG.17]



[FIG.18]

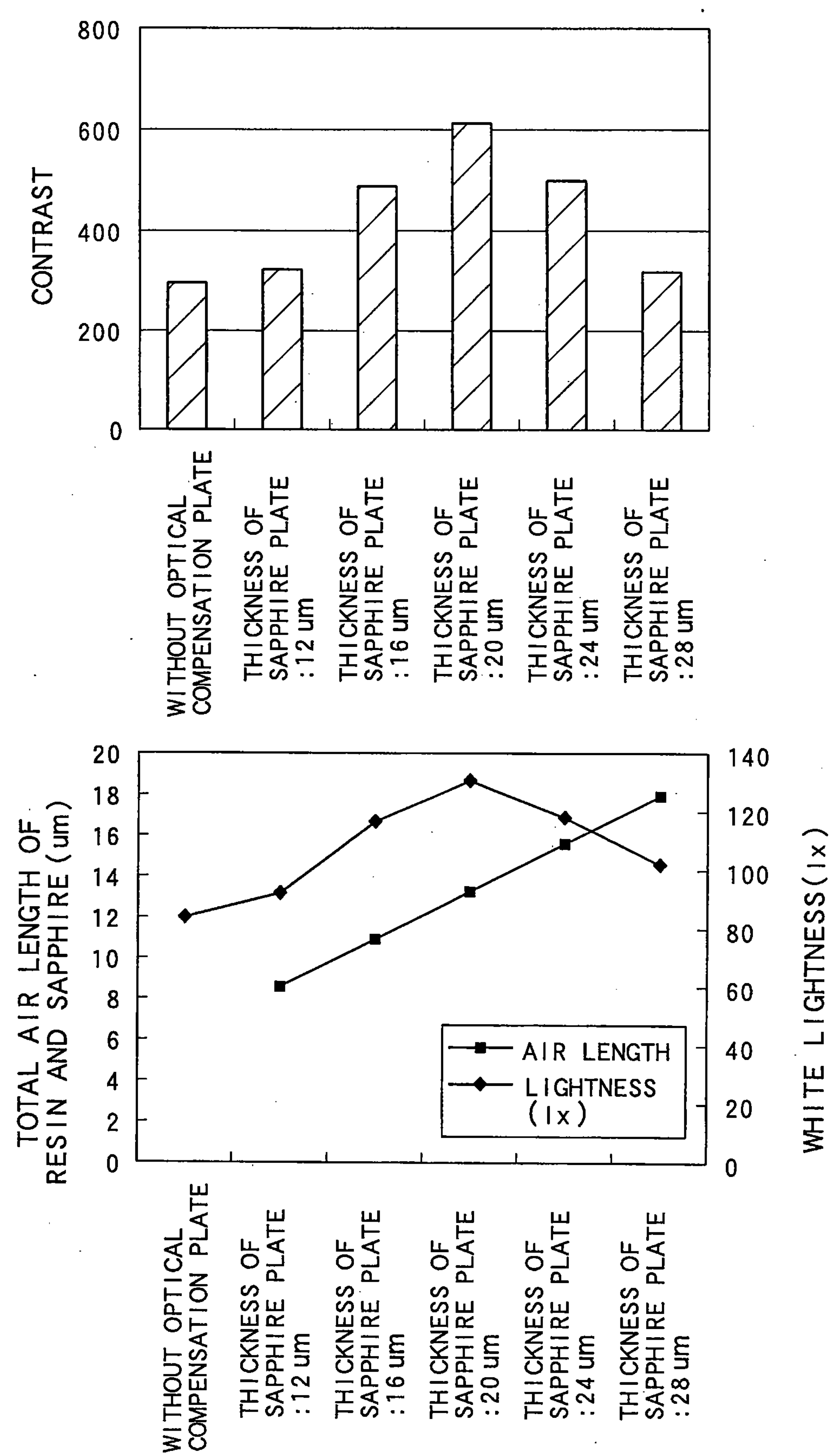

THICKNESS OF SAPPHIRE PLATE :d2
REFRACTIVE INDEX OF SAPPHIRE :n2
QUARTZ BOARD
RESIN THICKNESS :d1
REFRACTIVE INDEX OF RESIN :n1
AIR LENGTHS OF RESIN AND SAPPHIRE WITH REPSECT TO MICROLENS
d = d1 / n1 + d2 / n2

[FIG.19]



CONTRAST
800
600
400
200
0
WITHOUT OPTICAL COMPENSATION PLATE
THICKNESS OF SAPPHIRE PLATE :12 um
THICKNESS OF SAPPHIRE PLATE :16 um
THICKNESS OF SAPPHIRE PLATE :20 um
THICKNESS OF SAPPHIRE PLATE :24 um
THICKNESS OF SAPPHIRE PLATE :28 um
TOTAL AIR LENGTH OF RESIN AND SAPPHIRE (um)
24
22
20
18
16
14
12
WHITE LIGHTNESS (lx)
160
140
120
100
80
60
40
20
0
AIR LENGTH
LIGHTNESS (lx)
WITHOUT OPTICAL COMPENSATION PLATE
THICKNESS OF SAPPHIRE PLATE :12 um
THICKNESS OF SAPPHIRE PLATE :16 um
THICKNESS OF SAPPHIRE PLATE :20 um
THICKNESS OF SAPPHIRE PLATE :24 um
THICKNESS OF SAPPHIRE PLATE :28 um

[FIG.20]


CONTRAST
800
600
400
200
0
WITHOUT OPTICAL COMPENSATION PLATE
THICKNESS OF SAPPHIRE PLATE :12 um
THICKNESS OF SAPPHIRE PLATE :16 um
THICKNESS OF SAPPHIRE PLATE :20 um
THICKNESS OF SAPPHIRE PLATE :24 um
THICKNESS OF SAPPHIRE PLATE :28 um
TOTAL AIR LENGTH OF RESIN AND SAPPHIRE (um)
20
18
16
14
12
10
8
6
4
2
0
WHITE LIGHTNESS(lx)
140
120
100
80
60
40
20
0
AIR LENGTH
LIGHTNESS (lx)
WITHOUT OPTICAL COMPENSATION PLATE
THICKNESS OF SAPPHIRE PLATE :12 um
THICKNESS OF SAPPHIRE PLATE :16 um
THICKNESS OF SAPPHIRE PLATE :20 um
THICKNESS OF SAPPHIRE PLATE :24 um
THICKNESS OF SAPPHIRE PLATE :28 um

[Name of Document] ABSTRACT

[Summary]

[Task]

In the case where a liquid crystal display device is used as a spatial light modulator in an image display apparatus, it is possible to realize high contrast of displayed images without enlarging the structure of the image display apparatus and while maintaining sufficient long life time.

[Means for solution]

A liquid crystal display device is provided with a microlens array 7 on the luminous flux incidence side, and comprises optical compensation layers 4, 6 made of an inorganic material and having an optical axis inclined with respect to a liquid crystal panel surface, at least on either one of the luminous flux incidence side and a luminous flux emission side of the liquid crystal panel.

[Selected Drawing] Fig. 1

CLAIMS

1 A liquid crystal display device having a microlens array provided on a luminous flux incidence side,

the liquid crystal display device comprising an optical compensation plate made of an inorganic material at least on either one of the luminous flux incidence side and a luminous flux emission side of a liquid crystal panel, the optical compensation plate being cut out so that the direction of inclination angle of the optical axis with respect to outer shape of rectangle becomes in correspondence with rubbing direction of the liquid crystal panel with respect to the liquid crystal panel surface.

2 The liquid crystal display device according to claim 1,

wherein the inorganic material constituting the optical compensation plate is uniaxial crystal.

3 The liquid crystal display device according to claim 2,

wherein the inorganic material constituting the optical compensation plate is crystal or sapphire.

4 The liquid crystal display device according to claim 1,

wherein the direction of projection of optical axis of the optical compensation plate to the liquid crystal panel surface is substantially parallel to at least one of the direction of projection of pre-tilt of liquid crystal molecules near a board surface on the luminous flux incidence side of the

liquid crystal panel to the board surface and the direction of projection of the pre-tilt of liquid crystal molecules near the board surface on the luminous flux emission side of the liquid crystal panel to the board surface.

5 The liquid crystal display device according to claim 4,

wherein when refractive index anisotropy of the inorganic material constituting the optical compensation plate and refractive index anisotropy of a liquid crystal layer of the liquid crystal panel have the same sign, the optical axis of the optical compensation plate and the optical axis of the liquid crystal layer are inclined in directions opposite to each other with respect to the liquid crystal panel surface.

6 The liquid crystal display device according to claim 4,

wherein when refractive index anisotropy of the inorganic material constituting the optical compensation plate and refractive index anisotropy of a liquid crystal layer of the liquid crystal panel have different signs, the optical axis of the optical compensation plate and the optical axis of the liquid crystal layer are inclined in the same direction with respect to the liquid crystal panel surface.

7 The liquid crystal display device according to claim 1,

wherein the optical compensation plates are provided on both the luminous flux incidence side and the luminous flux emission side of the liquid crystal panel, and the direction of projection of optical axis of each of the

respective optical compensation plates is substantially parallel to the direction of projection of pre-tilt of liquid crystal molecules near a board surface on the luminous flux incidence side of the liquid crystal panel to the board surface and the direction of projection of pre-tilt of liquid crystal molecules near the board surface of the luminous flux emission side of the liquid crystal panel to the board surface.

8 The liquid crystal display device according to claim 1,

wherein the optical compensation plate has an external size equal to or larger than an effective display area of the liquid crystal panel.

9 The liquid crystal display device according to claim 1,

wherein the optical compensation plate is provided on a dustproof glass provided on the surface of the liquid crystal panel.

10 The liquid crystal display device according to claim 1,

wherein the optical compensation plate is provided on a cover glass of the microlens array.

11 A liquid crystal display device having a microlens array provided on a luminous flux incidence side,

wherein optical compensation plates of two lower structure made of an inorganic material are provided on the luminous flux incidence side of a liquid crystal panel surface, each of the compensation plates being cut out so that the direction of inclination angle of the optical axis with respect to outer

shape of rectangle becomes in correspondence with rubbing direction of the liquid crystal panel with respect to the liquid crystal panel.

12 An image display apparatus comprising:

a light source;

a liquid crystal display device having a microlens array provided on a luminous flux incidence side serving as a spatial light modulator;

an illuminating optical system for guiding a luminous flux emitted from the light source to the liquid crystal display device and thus illuminating the liquid crystal display device; and

an image-forming lens for forming an image of the liquid crystal display device,

the liquid crystal display device comprising an optical compensation plate made of an inorganic material at least on either one of the luminous flux incidence side and a luminous flux emission side, the optical compensation plate being cut out so that the direction of inclination angle of the optical axis with respect to outer shape of rectangle becomes in correspondence with rubbing direction of the liquid crystal panel with respect to the liquid crystal panel surface.

13 The image display apparatus according to claim 12,

wherein the inorganic material constituting the optical compensation plate of the liquid crystal display device is uniaxial crystal.

14 The image display apparatus according to claim 13,

wherein the inorganic material constituting the optical compensation plate of the liquid crystal display device is crystal or sapphire.

15 The image display apparatus according to claim 12,

wherein the direction of projection of optical axis of the optical compensation plate of the liquid crystal display device to the liquid crystal panel surface is substantially parallel to at least one of the direction of projection of pre-tilt of liquid crystal molecules near a board surface of the luminous flux incidence side of the liquid crystal panel to the board surface and the direction of projection of the pre-tilt of liquid crystal molecules near the board surface of the luminous flux emission side of the liquid crystal panel to the board surface.

16 The image display apparatus according to claim 15,

wherein when refractive index anisotropy of the inorganic material constituting the optical compensation plate of the liquid crystal display device and refractive index anisotropy of a liquid crystal layer of the liquid crystal panel have the same sign, the optical axis of the optical compensation plate and the optical axis of the liquid crystal layer are inclined in directions opposite to each other with respect to the liquid crystal panel surface.

17 The image display apparatus according to claim 15.

wherein when refractive index anisotropy of the inorganic material

constituting the optical compensation plate of the liquid crystal display device and refractive index anisotropy of a liquid crystal layer of the liquid crystal panel have different signs, the optical axis of the optical compensation plate and the optical axis of the liquid crystal layer are inclined in the same direction with respect to the liquid crystal panel surface.

18 The image display apparatus according to claim 12,

wherein the optical compensation plates of the liquid crystal display device are provided on both the luminous flux incidence side and the luminous flux emission side of the liquid crystal panel, and

the direction of projection of optical axis of the each of respective optical compensation plates is substantially in parallel to the direction of projection of pre-tilt of liquid crystal molecules near a board surface of the luminous flux incidence side of the liquid crystal panel and the direction of projection of the pre-tilt of liquid crystal molecules near the board surface on the luminous flux emission side of the liquid crystal panel.

19 The image display apparatus according to claim 12,

wherein the optical compensation plate of the liquid crystal device has an external size equal to or larger than an effective display area of the liquid crystal panel.

20 The image display apparatus according to claim 12,

wherein the optical compensation plate of the liquid crystal display

device is provided on a dustproof glass provided on the surface of the liquid crystal panel.

21 The image display apparatus according to claim 12,

wherein the optical compensation plate of the liquid crystal device is provided on a cover glass of the microlens array.

22 An image display apparatus comprising:

a light source;

a liquid crystal display device having a microlens array provided on a luminous flux incidence side serving as a spatial light modulator;

an illuminating optical system for guiding a luminous flux emitted from the light source to the liquid crystal display device and thus illuminating the liquid crystal display device; and

an image-forming lens for forming an image of the liquid crystal display device,

the liquid crystal display device comprising an optical compensation plate made of an inorganic material on the luminous flux incidence side of a liquid crystal panel surface, the optical compensation plate being cut out so that the direction of inclination angle of the optical axis with respect to outer shape of rectangle becomes in correspondence with rubbing direction of the liquid crystal panel with respect to the liquid crystal panel surface.